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DECLINE OF GREAT BASIN, SOUTHWESTERN UNITED STATES[1]

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ABSTRACT

The Great Basin district, during the Paleozoic and lower Mesozoic, was a geosynclinal area, in which 30,000 feet of sediments accumulated. The district was folded in the mid-Mesozoic revolution to form a mighty mountain system. It was thereafter degraded, during the Cretaceous and most of the Tertiary, to a region of low relief.

By Pliocene time the crust in the Pacific geosynclinal belt west of the Great Basin district had become so weakened that the intermediate Sierra Nevada massif began to creep westward under gravity. The Great Basin district followed, its crust was extended, and block-faulting commenced.

In the Pleistocene, western North America was epeirogenically uplifted, and as a result the gravity flow increased. The Sierra Nevada massif and its extensions moved westward as much as 60 miles, shortening the crust in California, and extending the crust in the Great Basin district, to that extent. The Great Basin District then collapsed, ponded its drainage, and occasioned a topographic discrepancy which caused the Grand Canyon of the Colorado to be cut.

This paper is a description of the major structural control in the southwestern United States. All structures in California now yielding oil and gas were formed under this control.

INTRODUCTION AND ACKNOWLEDGMENT

The chief stimulus for the present discussion has been the concluding paper by Gilbert,[3] repeated reading of this as a text-book on discourse

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[3]G. K. Gilbert, "Studies of Basin-Range Structure," *U. S. Geol. Survey Prof. Paper 153* (1928).

having led the writer to reflect on the relation which adjoining provinces bear to the Great Basin. A lecture by W. M. Davis provided the immediate spur. The trail herein followed leads back, however, many years, to a warm Wyoming summer spent with C. A. Bonine, the writer's first instructor in the field.

The purpose of the writer is to summarize the histories of the Rocky Mountain and Pacific provinces in relation to that of the Great Basin, and thus secure a connected picture which will give added information on all three. The history of the Rocky Mountain province is chiefly an integration of the work of others. That of the Pacific province is mostly integrative in its older parts, but in the younger Cenozoic part, the personal work of the writer is increasingly used.

GENERAL THEORY OF GREAT BASIN STRUCTURE

Figure 1 presents a physiographic outline of the Great Basin district and adjacent areas as they exist to-day.

The general theory of Great Basin structure as developed[1] by Gilbert, King, Dutton, Powell, Russell, Davis, Blackwelder, and Louderback, is briefly as follows. (1) During much of Paleozoic and lower Mesozoic time the site of the present Great Basin was a dominantly depressed area in which there accumulated a vast thickness of sediments. (2) At the close of the Jurassic this prodigious thickness of sediments was elevated, compressed, and folded into a region of high relief. (3) During Cretaceous and most of Tertiary time the area was degraded and practically peneplaned. (4) Tension commenced in the late Tertiary and progressed to a maximum in the Quaternary, with the result that the crust in the Great Basin district fell apart to form blocks, mostly tilted, which are now separated by faults of large throw.

King seems to have been the first to recognize the nature and magnitude of the ancient mountains. The idea that these were reduced to a condition of low relief before the period of block-faulting, Gilbert states to be "distinctly Dutton's addition." The conception that the final state was one of rejuvenation by block-faulting was contributed by Gilbert.

The general theory is summarized by King.[2] The Great Basin district was

[1] *Op. cit.*, pp. 1-9.

[2] Clarence King, *U. S. Geol. Explor. 40th Parallel Rept.*, Vol. 1 (1878), pp. 735-43. As quoted by Gilbert, *op. cit.*

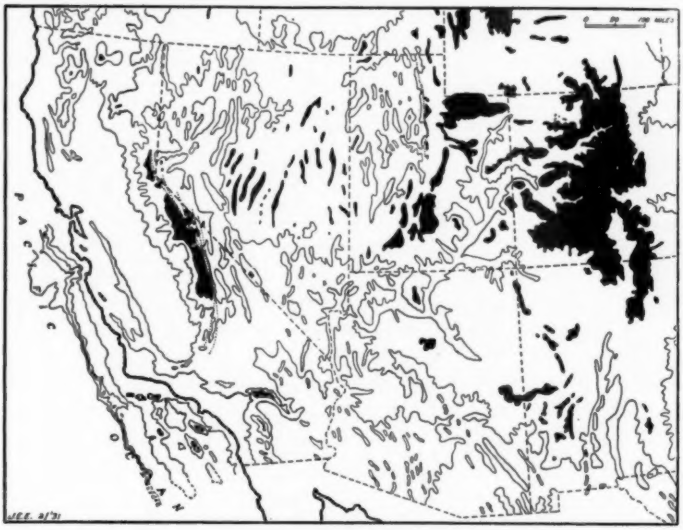

FIG. 1.—Southwestern United States. Contours of elevation drawn at 2,000 and 5,000 feet, with elevations more than 8,000 feet shown in black. Hydrographic contours sketched at −2,000, −5,000, −8,000, and −12,000 feet.

The Colorado Rockies stand out boldly east of Colorado River. The western Rockies appear less boldly through central Utah, west of the river. The Wasatch range is the minor chain along the eastern edge of Lake Bonneville, the frontal fault (after Gilbert) being indicated by a line of fine dots. The Sierra Nevada looms steeply along the east-central line of California, its frontal fault also being indicated by a line of dots. Between the Wasatch and the Sierra Nevada the higher Basin ranges appear as black slivers, with Lake Bonneville east and Lake Lahontan west of them.

Notice the abyssal scarp offshore, the transverse structural chain indicated by three islands and an inland range in line, and the drowned, incised deltas.

....A region of enormous and complicated folds, riven in later time by a vast series of vertical displacements, which have partly cleft the anticlinals down through their geological axes and partly cut the old folds diagonally or perpendicularly to their axes.....A continuous series of folds of Paleozoic and Mesozoic rocks....most irregularly invaded by a series of faults....The result of this complicated interlacing system of dislocation is that all the ranges of the Great Basin are broken into irregular blocks, sections of which have sunk many thousand feet below the level of adjoining members.....

That these faults were not contemporaneous with the great folding period is obvious from their relations to the axis.....When we remember that the Eocene and Miocene Tertiary rocks which have been laid down within the hol-

lows of these post-Jurassic folds have themselves been thrown into waves and inclined positions up to 40° and that these Tertiary beds are often violently faulted, it is evident that in extremely modern geological history there has been sufficient dynamic action to account for the system of faults.

EVIDENCE OF ADJACENT PROVINCES, EXCEPT CAUSE

Figure 2 shows the boundaries of the Great Basin structural district and adjacent provinces, and the relative thickness of Cretaceous deposits on the east and west.

The Great Basin district is bounded on the north and south by plateau provinces whose later sediments are only slightly deformed. Hence, the late release of pressure must have been toward the east or west. Assuming that the upper part of Figure 2 shows the only conditions of an abstract problem, a geologist, noticing the deep crease in the earth's crust on the west filled with incompetent sediments, would be justified in concluding that post-Cretaceous release of pressure in the Great Basin district would probably be toward the west.

The five cross sections forming the lower part of Figure 2 and summarizing progressive relations between the Great Basin district and adjoining provinces illustrate a later part of this paper, but may be briefly mentioned here. It is observed that, as the thickness of incompetent sediments increased in the Pacific province and progressively weakened the bulwark on the western side of the Sierra Nevada massif, the massif progressively tilted and moved westward, thus simultaneously causing compression on its west and tension on its east. The tilting (lesser) movement of the massif is shown in the figure. The horizontal (greater) movement is not shown, the cumulative amount at each stage being merely indicated by the length of horizontal arrows, and the amount between successive stages by the difference in the length of the arrows.

PALEOZOIC

Figure 3, *A*, is a generalization of Paleozoic palegeography in the Great Basin district and in California. The entire figure is based chiefly on the compilation by Smith,[1] with many data on the east side from Schuchert.[2]

[1]James Perrin Smith, *Geological Map of the State of California*, California State Min. Bur. (1916).

[2]Louis V. Pirsson and Charles Schuchert, *Text-Book of Geology*, John Wiley and Sons (New York, 1924).

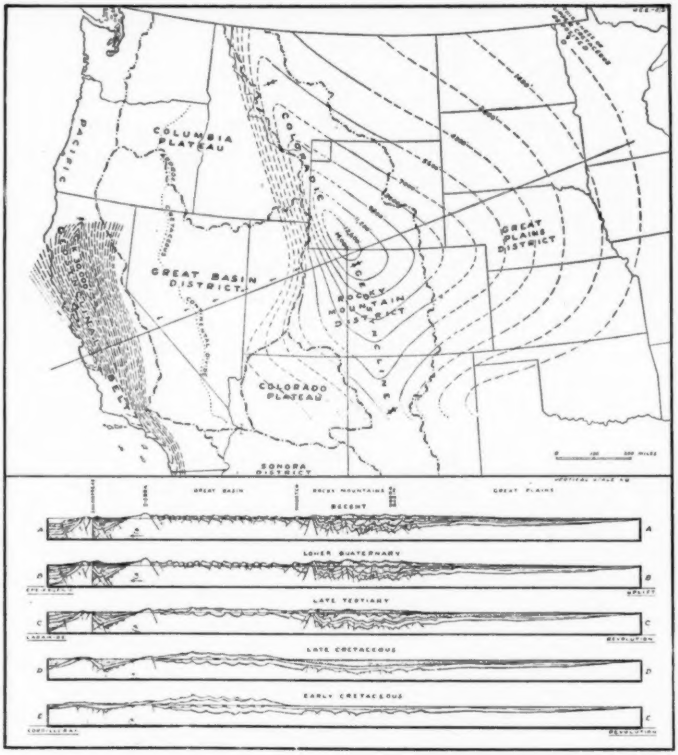

FIG. 2.—Contours on the east show comparative total subsidence below sea-level, and thickness of sediment deposited, in Upper Cretaceous time. Contours farther west in California represent the whole of Cretaceous time. The cross sections illustrate the progressive breaking down of the crystalline Pacific borderland, and the accelerated fall of the Sierra Nevada massif toward the sea with increasing compression on the west and tension on the east. The westward movement is not drawn, its cumulative amount being merely indicated by the length of the horizontal arrows.

The Paleozoic was so long that all parts of California may have been submerged and have emerged several times during the era, as indeed is known to have been the fact with most areas shown as submergent, but the generalization drawn is sufficiently accurate for present purposes. It illustrates the feature that the Great Basin district was prevailingly depressed in Paleozoic time and accumulated vast thicknesses of sediment, that the Colorado Plateau area was less depressed and re-

ceived thinner deposits, and that California was flooded to an important extent only during the Carboniferous transgression.

It should be noticed that there is no definite evidence of the Sierra Nevada massif as an individual unit, the Carboniferous sediments having been seemingly deposited as a sheet over its site and extending into northwestern California. However, the boundary between general and upper Paleozoic deposition, and that between the upper Paleozoic sea and the western borderland approximately delimit the Sierra Nevada massif. This may mean that the block was then outlined, or may only suggest the conditions which determined its subsequent outline.

The Sierra Nevada massif has been considered by some workers to be a batholith intruded at the close of the Carboniferous, and by others to be a batholith intruded at the close of the Jurassic. Intrusions of both ages are present.

The writer suggests that the massif, strictly defined, is not a batholith, but is a block of the basement which has been tilted up, fractured, and repeatedly intruded. It seems improbable to him that the bulk of this vast block, 500 miles long, 100 miles wide, and of unknown depth, was formed at so late a time as either the post-Jurassic or the post-Carboniferous, because (1) a liquid mass of material of that volume was obviously not then drawn laterally from another locality, (2) it seemingly did not then rise as a molten batholith, for to do so it must displace an approximately equal mass which would previously have been at and near the surface, and (3) it seemingly did not result from complete metamorphism of previously heterogeneous rocks of similar volume, for fusion of such magnitude should not stop at a level plane and leave unconsumed the sediments which now deeply cover the less eroded parts of the massif. The fatal objection to the batholith theory is, however, that the Carboniferous sediments seem to have been deposited on a virtually peneplaned surface, and that despite the inequality caused by later intrusions, the pre-Carboniferous surface remains obvious. A batholith 500 × 100 × ? miles should cause doming. It is inconceivable, to the writer, that a rising intrusive mass, more than 50,000 square miles in area, could stop everywhere at a level which, broadly seen, would give the effect of a peneplain.

The Sierra Nevada massif is considered in this paper as being an angular block of the pre-Paleozoic crust which has been tilted, fractured, and penetrated repeatedly by magmas which have risen along fissures. According to this interpretation, an original mass, too ancient to be dated, has been repeatedly intruded in known geologic time, and now has a

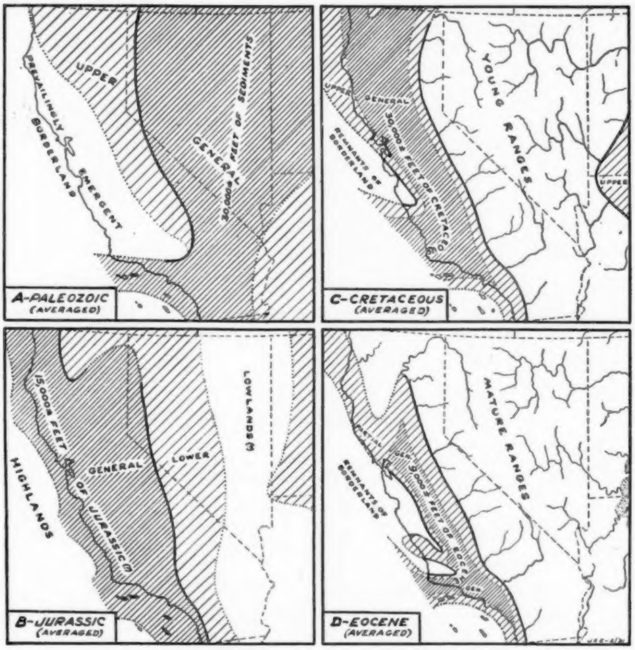

FIG. 3.—Paleogeographic glimpses much generalized to emphasize dominant sea and land phases. Epeiric seas lined, lakes dotted. The drainage is largely hypothetical.

Paleozoic land becomes Mesozoic sea; and Paleozoic sea, Mesozoic land; excepting in the transverse crease. Notice that this east-west seaway remains more or less continuously depressed, being gradually filled with sediments. In effect, a deep, transverse notch is being cut in the crust.

The extensive Paleozoic and lower Mesozoic borderland was split into two parts by the post-Jurassic revolution. The eastern part became the Sierra Nevada block and began a progressive westward tilt. The western part of the original borderland, shattered and partly broken down in the post-Jurassic revolution, has since progressively foundered (See Fig. 2).

surface which is almost entirely a mosaic composed of intrusions of different ages.

Regardless of its mode and date of origin, the Sierra Nevada massif is definitely a mass of a size approximating 500 × 100 × ? miles, which, through some favorable situation or condition, has acted essentially as a unit for tens of millions of years while adjacent parts of the crust have been split apart and have lost their unity.

The sources of material for the Paleozoic sediments deposited in and near the Great Basin district are only generally known. On the west the Pacific province and its adjacent borderland were prevailingly emergent. On the east much of what is now the Rocky Mountain province was emergent for long periods.

LOWER MESOZOIC

Figure 3, *B*, generalizes Jurassic paleogeography.

The lower Mesozoic, under which are grouped the Triassic and Jurassic periods, was essentially a long transition phase between the stage previously discussed and a revolution to come.

In the Great Basin district, widespread deposition continued during much of the lower Mesozoic, but near the end a considerable part of the district seems to have become emergent.

In the Pacific province the previous tendency toward emergence was gradually overcome, and in Jurassic (?) time practically all of California became submerged. Jurassic (?) sands, clays, and cherts as thick as 15,000 feet or more were laid down on a virtually peneplaned surface. The eastern California sediments (Mariposa) are Jurassic and marine; the western sediments (Franciscan) are not of a certainty Jurassic, nor are they of a certainty marine.

The chief source of materials for the California Jurassic (?) sediments was a large, granitic borderland which existed west of the present coast. Not only were there no land areas on the north, east, or south capable of furnishing the amount and kind of materials, but as Davis[1] has said of the sediments near the present coast:

> The mineralogical composition of the sandstone shows that it was derived from granitic rocks, and the angular nature of the grains indicates that they could not have travelled very far.

Davis suggests emergent granite of the Coast Ranges as a source of supply. However, the Franciscan seems to have been deposited as a sheet over what are now the Coast Ranges, and although the presence of locally emergent areas is assumed, all such areas combined could hardly have furnished more than 2 per cent of the total volume of the Franciscan sediments.

The Rocky Mountain province was reduced to a peneplain by the end of the Jurassic. This is indicated by thin but very extensive continental deposits of that age, and more particularly by the fact that

[1] E. F. Davis, "The Franciscan Sandstone," *California Univ. Dept. Geol. Bull.*, Vol. 11, No. 1 (1918), p. 30.

the first few hundred feet of Upper Cretaceous depression seems to have submerged the entire province.

MID-MESOZOIC (CORDILLERAN) REVOLUTION

Between the known Jurassic and known Cretaceous records of the western United States occurred the Cordilleran revolution. It reversed the rôle of the various provinces.

During this revolution the Great Basin district was compressed and its prodigious thickness of Paleozoic and lower Mesozoic sediments was folded into a system of mighty mountains. It became the "region of enormous and complicated folds" described by King. Measured by the amount of sedimentary material subsequently furnished adjoining provinces, the average elevation of the Great Basin, if attained at one time, would have been in excess of 15,000 feet, with peaks and valleys extending thousands of feet above and below this average. However, since the sediments of adjacent provinces indicate that elevation of the Great Basin district continued through much of the Cretaceous, contemporaneous erosion may have prevented such great heights at any one time.

In the Pacific part of California nearly all sediments then existing were more or less metamorphosed during the Cordilleran revolution. The Sierra Nevada massif was intruded by magmas chiefly of an acidic nature. The coastal areas were intruded by magmas chiefly of a basic nature. Metamorphism was strong in some parts and weak in others, but it was extensive enough to destroy most evidence of age, and to necessitate the indefinite term "pre-Cretaceous" in reference to many of the older sediments of the Pacific province. No oil has been found below the Cretaceous in California, and probably little will be found. In coastal areas the Jurassic (?) sediments have a burnt aspect or sheen which permits them to be readily differentiated from Cretaceous sediments of somewhat the same composition.

Dated sedimentation in the Pacific province is chiefly subsequent to the Cordilleran revolution. But this subsequent record is enormous, for the province then began to founder and the seas seldom left its deeps. For nearly every period and epoch subsequent to the Jurassic the Pacific province with its 75,000 feet of Cretaceous and Cenozoic sediments furnishes the maximum known marine record of the world.

The Sierra Nevada massif, whatever its former history, has acted as a unit since Jurassic time, for all subsequent deposition reveals a progressive downtilting of its western edge (Fig. 2, sections; Fig. 3, *C* and *D*; and Figs 5 and 6).

In contrast to these revolutionary effects in the Great Basin and Pacific provinces, the Rocky Mountain province passed through the Cordilleran revolution with little disturbance, there being at most a slight fracturing. Being an area with only a thin veneer of plastic sediments on a great thickness of ancient, hardened rocks, it acted as a buffer. A geologist examining this province alone would never suspect that geosynclinal areas farther west had suffered a revolution.

The plateau provinces north and south of the Great Basin district were also little affected, probably because of the comparative thinness there of incompetent sediments. Attention is called to the feature that in all areas the degree of deformation during the Cordilleran revolution closely paralleled the thickness of incompetent sediments.

CRETACEOUS

In Cretaceous time the Great Basin district was a highly elevated region which furnished vast quantities of sediment to the Rocky Mountain and Pacific provinces, thus reversing the relation during the Paleozoic and lower Mesozoic. Figure 3, *C*, generalizes Cretaceous paleogeography on the west. The drainage is hypothetical.

Nearly all of California lying in the Pacific province was covered by the sea during much of the Cretaceous. Cretaceous sediments were laid down in a trough extending lengthwise through the state, their thickness reaching 30,000 feet or more at its center, and thinning outward in all directions (see contours showing comparative thickness in Figure 2).

Both Lower and Upper Cretaceous are represented. The two have not been accurately separated in California, no comprehensive investigation of the system there having yet been made. The middle deposits have been referred by some workers to the Lower Cretaceous, and by others to the Upper. As a rule, the older work assigned the doubtful strata to the Lower Cretaceous. More recently, Pack and English,[1] in describing 25,900 feet of Cretaceous rocks in middle California, assign the basal 3,500 feet to the Lower, and the highest 4,800 feet to the Upper Cretaceous, and infer that the thick middle division is perhaps also Upper Cretaceous. They state that

> Upper Cretaceous fossils have been found in the middle of the three divisions ....Only two fossils have been found in the upper part of the lower division. These....although not diagnostic, suggest Upper Cretaceous rather than Lower Cretaceous age.

[1]R. W. Pack and W. A. English, "Waltham, Priest, Bitterwater, and Peachtree Valleys, California," *U. S. Geol. Survey Bull. 581-D* (1914), pp. 127-29.

The writer infers from regional considerations that subsequent studies of maximum Cretaceous sections in California will show the bulk of their sediments to be Upper Cretaceous in age.

The Cretaceous materials seem to have come almost entirely from the rising Great Basin highlands on the east (Fig. 3, *C*). The sediments coarsen in that direction. Some material perhaps came from the western borderland, but this had in large part foundered during the Cordilleran revolution, and the remnants that remained above sea-level were presumably reduced to low relief in early Cretaceous time.

If it is assumed that 90 per cent of the Cretaceous materials came from the east, the Great Basin highlands west of the ancient continental divide (Fig. 2) would have been degraded an average of approximately 12,000 feet during the Cretaceous. This may give some idea of the magnitude of the ancient Great Basin highlands, and of the length of the Cretaceous period.

In the Rocky Mountain province the marine record is essentially that of Upper Cretaceous time, although some workers assign the basal few hundred feet of sediments to the lower division. The feature that thin continental deposits of Lower (?) Cretaceous age and the basal marine sediments which follow them are both of only moderate coarseness indicates that the Great Basin highlands did not reach their maximum height before the Upper Cretaceous. The evidence of the Rocky Mountain province, corroborated in part by the record of the Pacific province, indicates that the Great Basin highlands grew during much of the Cretaceous.

The Upper Cretaceous sea rapidly transgressed the peneplaned surface of the Rocky Mountain province, a few hundred feet of subsidence being sufficient to submerge almost the entire region. The basal deposits (which are partly non-marine and may be late Lower Cretaceous) are dominantly sands, with a pebbly content on the west. Above these are many thousand feet of coarse and fine sediments.

In the Rocky Mountain province as a whole the averaged sedimentary column becomes coarser upward. A too simple interpretation of this feature is that the highlands on the west, which furnished the bulk of the material, increased throughout the Cretaceous. However, a slowing of the rate of subsidence of the sea bottom in late Cretaceous time could give this aspect without the necessity of increased erosion on the land. As the writer[1] has elsewhere illustrated, texture of marine sediment in

[1]J. E. Eaton, "The By-Passing and Discontinuous Deposition of Sedimentary Materials," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), p. 739.

a basin receiving an excess of materials is a compromise between rate of erosion on the land and rate of subsidence of the sea bottom, a decrease of the rate of subsidence by half being approximately equal to a doubling of the rate of erosion on the land as far as texture and allied features are concerned. Regionally coarser or finer sedimentation in epeiric seas more commonly represents change in rate of basin subsidence than change in intake of materials. We expect regional subsidence to decrease near the end of a depositional cycle. In the region under discussion the expected decrease in rate of subsidence is ample to explain the coarsening of texture without an increased intake or coarsening of materials.

The materials for the Upper Cretaceous sediments of the Rocky Mountain province came chiefly from the west, as King early recognized and as is obvious from the direction of gradation. There is no way of determining precisely what percentage of the materials was supplied by the Great Basin district. Prorated on area, the part of the Great Basin district east of the ancient continental divide (Fig. 2) would have furnished approximately 25 per cent of all of the materials deposited in the Coloradic geosyncline. Considering that the district was much more corrugated and of higher relief than were the less disturbed provinces on its north and south, we should increase the percentage mentioned to perhaps 40 per cent.

Figure 2 is contoured to show the comparative thickness, in the Rocky Mountain province, of the undisputed Upper Cretaceous sediments of Colorado and Montana age, based on the less eroded deposits described in publications of the United States Geological Survey. On the assumption that 80 per cent of the materials came from the west and that 40 per cent of this originated in the Great Basin highlands, the Great Basin district east of the ancient continental divide was degraded an average of 9,000 feet during Upper Cretaceous time. If higher, disputed sediments commonly assigned to the Cretaceous are included, the estimate of degradation must be increased. Thus, the eastern geosyncline, like the Pacific province, illustrates both the magnitude of the ancient Great Basin highlands and the considerable length of the Cretaceous period.

POST-CRETACEOUS (LARAMIDE) REVOLUTION

The Laramide revolution folded the Cretaceous sediments along the axis of the eastern geosyncline into an early form of the Rocky Mountains, and there caused pronounced unconformity between the Cretaceous and the Eocene sediments. Outer, shallow parts of the

geosyncline were only slightly disturbed, and in these localities the break was a disconformity, thus again illustrating Hall's law that zones of maximum sedimentation become zones of major folding (see Rocky Mountain boundary, Figure 2, in relation to the geosyncline).

In the Pacific province the Laramide revolution produced nearly the same result—folding and angular unconformity in the deeps, with stability and disconformity on edges.

The Great Basin district was thus one of the hardened, long-emergent buffers, and as such seems to have been comparatively little affected.

EOCENE

In Eocene time the Rocky Mountain province accumulated lacustrine sediments in broad, shallow lakes between emergent ranges raised by the Laramide diastrophism. The Eocene deposits are more irregular in thickness and texture than those of the Cretaceous, partly because of their being more or less intermontane. Although locally rivaling the Cretaceous deposits in thickness, the Eocene deposits are as an aggregate much less imposing, because of their localized magnitude and occurrence. The comparative totals are somewhat vague and difficult to estimate, but the aggregate volume of Eocene sediment can scarcely have been more than 20 per cent that of the Upper Cretaceous, and may have been much less. As some of the Eocene material was derived from locally emergent Upper Cretaceous rocks, the relative degradation of the Great Basin district was, comparatively, of still less importance. Decreased erosion in the Eocene would be expected because the Great Basin district had become relatively lower and the Rocky Mountain province higher, thus reducing the grade of streams.

Figure 3, *D*, generalizes Eocene paleogeography in California. The drainage is largely hypothetical.

The Eocene series in California is chiefly marine, thicknesses as great as 9,000 feet being known, and 14,000 feet reported. The Eocene basin approximated that of the Cretaceous in form, but was smaller, and had a total volume of sediments only about 15 per cent as large. Most of the material came from the Great Basin district, with comparatively small quantities from the then low Sierra Nevada and emergent areas near the present coast.

By the close of Eocene time the mighty mountain system of the Great Basin district was eroded, and the province was again approaching low relief. The part west of the ancient continental divide had been degraded approximately 13,000 feet, and that east of the divide, 11,000

feet, since the close of the Jurassic. The mountain ranges of the Great Basin district were now old, worn stumps, their majestic peaks and ridges of yesterday scattered as fragments carpeting the Rocky Mountain and Pacific provinces to a depth of several miles. The rocks had merely come home. In conformity with the cycle of the ages, the adjoining provinces had given; then taken away.

OLIGOCENE AND MIOCENE

In the Oligocene and Miocene smoothing erosive touches were put upon the Great Basin district. The district was in these times so low and so nearly base leveled that it ceased to contribute material to the Rocky Mountain province. The streams which had formerly discharged into the eastern geosyncline were now diverted north and south by the rising Rocky Mountains, to wind in a half-circle through the plateau provinces and at last reach the Pacific (Fig. 5, *A*). They were not the swift-flowing rivers of the past, but sluggish, meandering waters which perhaps disappeared in dry seasons.

The continental divide had moved eastward approximately 500 miles, and the Great Basin district was now wholly within the Pacific watershed. The old continental divide was marooned as a low swell of rounded topographic forms. It sent sluggish, intermittent streams in all directions, but all of these wound circuitously to the Pacific. It is to be noticed that the drainage which now flows southwest as the Colorado River system flowed northeast in Cretaceous and Eocene time. The direction of flow was reversed between Eocene and Pleistocene time (compare Figure 3, *D*, with Figures 5 and 6). This complete reversal of drainage implies that for a very long time there was no real river flowing in either direction, but that there was a stagnant desert basin without perennial streams.

The California sedimentary record faithfully chronicles this senility, for much of the drainage from the western part of the Great Basin district wound around the ends of the then low Sierra Nevada block (and possibly across it), and flowed through the state.

The Oligocene deposits of California are of small volume and occurrence and are in large part non-marine, the area of the state having been epeirogenically uplifted in this epoch to form broad, flat lowlands. Under this condition California retained only the coarsest of the materials received. But the coarser materials were chiefly sand, there being comparatively little conglomerate, and this little was probably reworked material from the edges of the state.

In the Miocene the sea invaded California widely. The state sank rather steadily during the first half of the epoch, emerged, and was flooded again twice during the upper Miocene. The Miocene series has a sandy base, and becomes fine-grained upward, though near its top there are coarse, granitic sands which were locally derived.

In the upper Miocene, enormous quantities of basic lavas were poured out in the Cordilleran region, most of the Columbia Plateau province north of the Great Basin district being covered by basaltic sheets to a depth of several thousand feet, and much of the Great Basin to a less extent. The maximum volcanism is dated as early upper Miocene (Monterey) by the California marine succession,[1] the 5,000 feet of sediments of that age being derived in large part from volcanic ash.

The slight relief which remained in the Great Basin district was almost obliterated by the flows of upper Miocene time. The extensive area covered by thin sheets shows that the surface over which the lavas advanced was nearly peneplaned. At the close of the Miocene volcanism the Great Basin district was a flat, almost formless waste, with perhaps here and there the worn stump of some ancient mountain range projecting as a low swell above the level expanse of lava.

PLIOCENE AND PLEISTOCENE

In the Pliocene, and particularly in the Pleistocene, occurred events which changed the flat expanse into the rugged region of ridges alternating with deep alluvial fills which characterizes the Great Basin district to-day. The cause and chronology of these events are discussed in a later part of this paper, only the occurrence and recognition being discussed here.

The collapse of the crust in the Great Basin district began in Pliocene time and progressed to a maximum in the Pleistocene. The structural features have been fully discussed by Gilbert, King, Dutton, Powell, and Russell, the criteria by Davis and Gilbert, and examples by Blackwelder, Louderback, and others. For a summary of the dominant structure and of criteria for its recognition, the reader is referred to the concluding exposition by Gilbert,[2] which is one of the most beautiful and unprejudiced things in the literature.

[1]Regional mapping by the writer reveals that more than 95 per cent of the California volcanism occurred in the upper Miocene, with fully 80 per cent concentrated in the early upper Miocene (Monterey). The Miocene is discussed in two halves; upper and lower.

[2]G. K. Gilbert, "Studies of Basin-Range Structure," *U. S. Geol. Survey Prof. Paper 153* (1928).

The crust in the district fell apart to form blocks, commonly tilted and asymmetric, with a short, steep face revealed by a frontal fault, and a long, gentler reverse slope which in many places reveals traces of the old Miocene peneplain.

That the block-faulting did not begin before the late Tertiary was early inferred from the fact that the flat-laid upper Miocene lavas were involved. Most investigators have concluded that the major faulting was of geologically recent date, and that the general process is active to-day.

King,[1] noting that Miocene beds are involved, states that "in extremely modern geological history there has been sufficient dynamic action to account for the system of faults."

Gilbert does not date the period of maximum block-faulting in publications known to the writer, but contents himself with conveying the impression that normal faulting began in the upper Tertiary and has continued to the present.

Dutton[2] concluded that the Grand Canyon of the Colorado is not older than the Pliocene, and because the major elevation and fracturing were contemporaneous with the canyon cutting, assigned these to the Pliocene. However, as Blackwelder[3] has now shown that the lower Colorado River did not exist in Pliocene time, Dutton's dating of the period of major fracturing was in effect Pleistocene.

Louderback[4] has systematically examined the evidence bearing on the date of inception. He concludes that "the period of faulting that produced the Basin Range scarps. . . . was begun in late Pliocene or early Pleistocene time." He places the maximum in the Pleistocene.

Davis[5] informs the writer that the chief erosion of the fault scarps was "probably Pleistocene."

Blackwelder, if he follows the inevitable chain of reasoning which is implied by his later discoveries,[6] seemingly must assign the maximum block-faulting to the Pleistocene.

[1]Clarence King, *op. cit.*

[2]C. E. Dutton, "The Physical Geology of the Grand Canyon District," *U. S. Geol. Survey Ann. Rept. 2* (1882).

[3]Eliot Blackwelder, "Physiographic History of the Colorado River," *Geol. Soc. Amer.*, Pasadena meeting, March 6, 1931; and personal communication, March 14, 1931.

[4]G. D. Louderback, "Period of Scarp Production in the Great Basin," *California Univ. Dept. Geol. Bull.*, Vol. 15, No. 1 (1924), p. 5.

[5]W. M. Davis, oral communication, January, 1931.

[6]Eliot Blackwelder, *op. cit.*

A Pleistocene date for the period of maximum fracturing is in accord with a world-wide uplift. Most of the present rugged mountains of the earth are the result of tremendous Pleistocene rejuvenation of diastrophism along lines of weakness inherited from the Tertiary. The bold fronts which now rise abruptly from adjacent plains on all continents can not be remnants from the Tertiary. They tell of recent uplift of such swiftness that it has dwarfed the powers of erosion.

THEORY OF CAUSE

On comparing the late Cenozoic structural histories of the Great Basin district and Pacific province, the writer has noticed a parallelism in the form of opposite reactions occurring at the same time. Both regions were structurally comparatively quiet in the Miocene. In the early Pliocene perceptible compression and shortening began in California, and Plilcene is the most commonly assigned date for the inception of perceptible tension, extension, and fracture in the Great Basin district. The major compression and shortening of California was certainly Pleistocene, and this is the date generally assigned for the major tension, extension, and fracture of the Great Basin district.

The dates for a Pliocene inception and Pleistocene maximum of compression and shortening in California are based on the world's finest known Cenozoic marine record. The date for inception of perceptible block-faulting in the Great Basin is based on the relation which upper Miocene lavas and early Pliocene sediments older than the faulting bear to the faulting, and the date for its maximum is based on the cutting and fracturing of the Grand Canyon of the Colorado, now known to have been Pleistocene. The time parallelism of these events in the two provinces is well evidenced.

The pivot between the contemporaneous but opposite structural reactions of the Pacific province on the west and the Great Basin district on the east was the intermediate Sierra Nevada massif and its general line of extension north into Oregon and south into Mexico.

The crust west of the Sierra Nevada massif has been shortened 60 miles, and the crust east of it has been extended perhaps an equal distance, in late geologic time. The two processes began more or less simultaneously, and thereafter progressed as opposite reactions at approximately the same rate to a peak of similar magnitude. Westward movement of the pivotal mass explains these simultaneous, opposite reactions. All observed evidence is in harmony with this postulate. It reveals step by step why and how the westward movement occurred.

THESES

Some structural theses of the writer are here stated.

1. Compression and shortening in California and tension and extension in the Great Basin district during upper Cenozoic time occurred simultaneously as a result of westward movement in which the Sierra Nevada massif and its extensions were the structural pivot (sections, Fig. 2; also Figs. 4, 5, and 6). Compression and tension were not qualitatively due to peculiarity of the Sierra Nevada massif, for the principle was the common one of gravity, but their quantitative magnitude which causes the coastal shortening in California and crustal extension in the Great Basin district to represent extremes has resulted partly from a unity and environment of the Sierra Nevada massif which has applied the principle of gravity more effectively than in most regions of the earth.

2. Certain southerly parts of the Sierra Nevada massif moved farther than did northerly parts (Figs. 4, 5, and 6). The line of maximum crustal tension and extension in the Great Basin district, along which occurs the maximum width of the basin, is a gentle arc curving east and north from the average center for movement of the massif to the northeast corner of the basin proper (Fig. 2).

3. The westward movement of the Sierra Nevada massif coincided with a less extensive westward movement of adjoining masses in general line with its axis in such a manner that, while there was some slippage[1] along the southern edge of the massif, the movement was somewhat similar to that when folding doors are opened (Figs. 4, 5, and 6).

4. The major structural and physiographic features of the Great Basin district as these exist to-day, that is, extreme block-faulting (sections, Fig. 2) and basin shape with ponded drainage (Fig. 1), are caused by an extension of its crust attended by progressive collapse. The process involved is widespread in earth history, the present example merely representing natural phenomena which have been carried to last stages, and which thus present an extreme, ideal illustration of a common geologic process whose effects are elsewhere less obvious.

SUMMARY OF EVIDENCE

Since the compression and shortening west of the Sierra Nevada massif and the tension and extension east of it are established features

[1] C. D. Hulin, "Geology and Ore Deposits of the Randsburg Quadrangle, California," *California State Min. Bur. Bull. 95* (1925), pp. 63, 64, 68, reports 5 miles of horizontal movement, chiefly Quaternary, along the Garlock boundary fault. The south side moved relatively east.

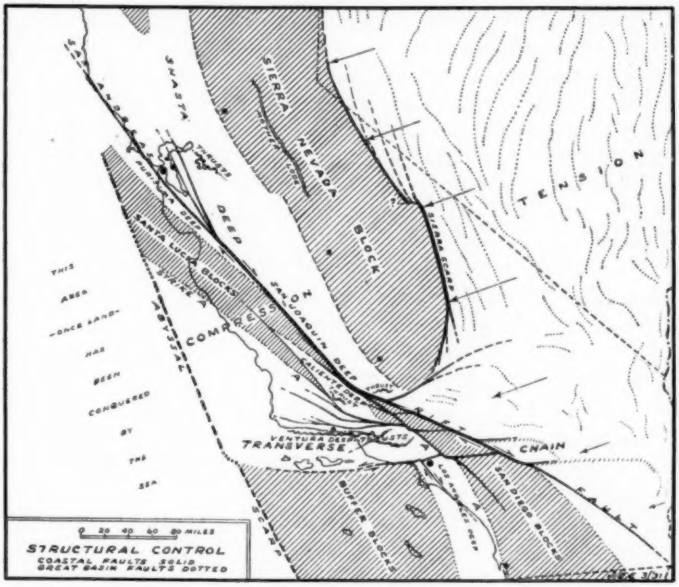

FIG. 4.—Structural control. The more rigid coastal areas are ruled, but the more plastic coastal areas and all of the Great Basin district are left blank. The chief coastal faults are shown by solid, and the chief Great Basin faults by dotted, lines.

The maximum coastal shortening occurs approximately from the southern tip of the Sierra Nevada block southwestward to the jog in the abyssal scarp, this coinciding with the maximum bend in the San Andreas rift, and with the line of maximum westward movement. All three features decrease northwest and southeast of the mutual maximum. Arrows drawn along the eastern side of the Sierra Nevada block and its extensions show the increase and decrease for all three.

The principal faults within the triangle have been bent into arcs projecting southwestward. The arcs are most pronounced near the maximum bend in the San Andreas rift, and are more gentle southwest from it. The overthrusts shown all ride southwestward, excepting the small one near the southern tip of the Sierra Nevada massif, which is necessarily reversed.

which agree in time, place, and amount with the postulated westward movement, it remains only to show that the movement actually occurred, and at times and in amounts consistent with the known results, in order to establish the validity of the concepts.

Sedimentation.—The cross sections on Figure 2, commencing at *EE* and progressing upward to *AA*, illustrate the progressive breakdown of a western bulwark confining the Sierra Nevada massif. The paleogeography of Paleozoic time indicates, and the western source for

the huge volume of Jurassic (?) granitic material definitely shows, that this western bulwark was in those early times a relatively immovable body of great rigidity and strength.

In the early Cretaceous (*EE*) this western bulwark was still essentially intact, but the strains of the Cordilleran revolution had split it longitudinally into two or more parts. The eastern part (Sierra Nevada block) had begun to tilt very gently toward the west as a result of gravity, there being approximately 3 miles difference in elevation between the areas east and west of it.

During the Cretaceous (*DD*) the western bulwark partly disintegrated and weakened. Gravity slowly tilted the Sierra Nevada block westward, thus inaugurating the great central geosyncline of California and causing the more western part of the bulwark to become a borderland. The outer bulwark was then too strong to admit of perceptible horizontal movement. However, much of it was broken down during the Cretaceous and replaced by several miles of weak sediments.

In Tertiary time (*CC*) the relations previously described continued, but the rate of change was accelerated. The bulwark disintegrated more rapidly under persistent pressure from the east and decreased western support. By the close of the Miocene, 30,000 feet of relatively coarse sediments had accumulated in the trough between the Sierra Nevada massif and the outer bulwark, and on the outer edges and west of the sinking borderland the finer-grained material should have accumulated to a somewhat similar thickness.

The strong, crystalline bulwark of old had almost disappeared in late Tertiary time and had been replaced by a vast expanse of weak sediments. Elongate, unsupported slivers of the basement, upthrown by differential movement, projected here and there through the expanse of sediment and gave it some support, but these crystalline slivers formed a relatively small proportion of the upper several miles of crust.

In brief, a region which had once been one of the strong parts of the earth—which had resisted, repeatedly, the mighty revolutions of the Paleozoic—had been converted into the weakest of known types (a geosyncline), and lay the prey of the first revolution to come.

The date at which resistance declined to the point where lateral pressure by gravity became irresistible is known to have been early Pliocene. Prior to that time the Tertiary unconformities in the California stratigraphic column were not perceptibly angular except for local adjustment in some deeps. The pre-Pliocene sediments were laid down in fairly wide basins of comparatively low structural curve, and local

faulting and tilting accounts for what little deformation occurred in post-Cretaceous and pre-Pliocene time. The Sierra Nevada massif, though tilting slightly, had not moved laterally to any great extent up to the close of the Miocene.

Commencing with Pliocene time, the basins of deposition became deep and narrow creases of high structural curve, they and the emergent areas between them began to be folded, and coastal California was shortened west of the Sierra Nevada massif at rates and to amounts later described.

What seems to have happened was this. The difference in elevation between the surface of the Great Basin district and the surface of the rigid basement of the outer bulwark, approximately 3 miles in early Cretaceous time, had increased in effect to 6 miles in the early Pliocene. Although the Great Basin district had been lowered by erosion approximately 13,000 feet, the basement of the outer bulwark had sunk approximately 30,000 feet, and the plastic sediments deposited to that thickness placed little resistance between the Sierra Nevada massif and the abyss.

The Sierra Nevada block was in effect poised on the edge of the abyss, with a peneplaned upland perhaps a mile high pressing on its eastern side, and on its west a region near sea-level with several miles of sediment—geologically so much jelly—interposed between it and the Pacific deep. Under such a condition, a region acts, slowly but inevitably, like an unstable hillside. It creeps. It has a front which is overridden by the advancing weight of the whole, a medial axis, and a rear which draws apart to leave potential voids which are filled by collapse.

The principle is old. It applies to all highlands adjacent to deeps, the present application being merely an obvious example. The heights which we see around us stand by reason of inward strength or outer bulwarks. When gravity overcomes such, the heights move toward the point of least resistance. We are dealing in this paper with a gigantic landslide. The Pacific province is its overriden and compressed front, the Sierra Nevada massif and extensions are its medial axis, and the Great Basin district is its extended rear where the potential voids are being filled by collapse.

The sedimentary record in California reveals the long, preparatory breaking down of resistance to movement, effected by replacing a rigid, crystalline bulwark with one composed chiefly of plastic sediments.

Compression.—As a result of comparing the relative attitude of beds of different ages in California for 10 years, the writer finds that approximately 10 per cent of the Cenozoic deformation and shortening of Cali-

fornia occurred in the Eocene, Oligocene, and Miocene combined, 20 per cent in the Pliocene, and 70 per cent in the Pleistocene. While precise percentages may be argued, those given are reasonably correct. Aside from deformations obviously of local extent and origin, if the Eocene series dips 60°, the average dip of the late Miocene is perhaps 55°, the late Pliocene 45°, and the late lower Pleistocene 42°. There are local variations, these representing merely comparative averages.

Figure 4 outlines the major structure of California and of adjacent parts of the Great Basin district. The maximum Cenozoic shortening of California has occurred westward from the southern tip of the Sierra Nevada massif, approximately on a line from this tip to the jog in the abyssal scarp. Deformation and shortening decrease slowly northwest of this line and rapidly southeast of it. The arrows along the eastern side of the Sierra Nevada block have been based on the amount of shortening in the coastal areas (the continental shelf has been prorated), their length in each case being the computed amount of post-Miocene shortening in the respective coastal areas opposite them.

Comparison of the length of the arrows shows that most of the shortening occurred opposite the Sierra Nevada massif, that the amount increases slowly from north to south until it reaches a maximum west of the southern end of the massif, and that it then decreases rapidly farther south as the zone of the massive buffer blocks is entered. The bend in the San Andreas rift fault (post-Miocene) increases and decreases in proportion to the increase and decrease of crustal shortening in the areas west of the rift. The bend in the abyssal scarp in the outer zone of lesser deformation shows the same relation.

1. The amount of crustal shortening in, and west of, California in post-Miocene time is the difference between the length of a cross section now, and its length if the post-Miocene folds were flattened out. It may be as much as 60 miles. This means 60 miles of lateral movement.

2. Because the sediments as a whole are less strongly deformed westward, because the main faults and thrusts form arcs projecting westward, and because the higher elevations are everywhere on the east, the inference is that the surface pressure came from the east, and that the surface movement has been toward the west.

3. Because the main coastal shortening and Great Basin extension are known to have been post-Miocene and contemporaneous, the inference is that these opposite reactions were simultaneously effected by one cause.

4. Because all evidence points to westward movement, because such movement explains all observed phenomena, and there seems to be no other adequate explanation of the phenomena, a westward movement of the surface is indicated.

The movement of the axial Sierra Nevada massif has been of several kinds, only two of which enter materially into the present problem.

The general block has been tilting westward since the early Cretaceous, the greater part of this tilting having occurred in the Pleistocene. The southern half of the massif has been tilted and eroded more than the northern half, which implies that the whole has been split into two or more parts by cross-faulting. Tilting alone could hardly have caused the intense crustal shortening farther west, which, as stated, locally approximates 60 miles. If the Sierra Nevada massif is 20 miles deep, the maximum shortening referable to its tilt is less than 1 mile, or less than 1 per cent of the required amount. The massif would have to be more than 2,000 miles deep for the post-Miocene tilting alone (less than $3°$ for the south half as a whole) to be the sole cause of shortening, a depth which is manifestly improbable.

The writer estimates that approximately 99 per cent of the coastal shortening has resulted from a lateral sliding of the entire massif westward. The mechanics is unknown, but since the massif generally held together and moved more or less as a unit, the plane of slippage seems to have offered little resistance. It is possible that this plane marks some layering in the crust.

San Andreas rift.—The San Andreas rift fault is the northwest-striking master shear along which differential horizontal movement developing at a right angle to the much greater southwestward movement is equalized. By examining Figure 4 the reader will see that the crustal area bounded by the abyssal scarp, the San Andreas rift, and the buffer blocks, is a triangle which is being irresistibly pressed upon from the northeast, with little or no relief on the south. Under these conditions, the triangular area has necessarily moved westward relative to the buffer blocks, and northwestward relative to the Sierra Nevada block and environs. The relative movements (Fig. 4) are visible along the boundary lines and are expressed between them by an *en échelon* arrangement of the minor structure. All observed relations are in accord with the postulates.

The resistance to movement of the triangular area has created back pressure, with the result that the plastic surface of the triangle has been highly folded, overthrust, and thereby shortened. The line of maximum

shortening is the line of maximum movement southwestward. As the crust west of the San Andreas rift shortens unequally, the rift bends southwestward. The amount by which the rift deviates at any point from a straight line corresponds with the amount of crustal shortening southwest of it, the maximum bend in the rift being crossed by the line of maximum crustal shortening, with both bend and shortening decreasing northwest and southeast of the maximum.

Kerr and Schenck[1] have recognized that, in south-central parts of the triangle,

> The main trend of the structural axes is parallel to the trace of the San Andreas fault, a curve in the direction of the fault being accompanied by a corresponding curve in strike lines of adjacent structural features.....The major release of pressure on overthrust blocks is probably from inland toward the coast.

Within the triangle are smaller rift faults which adjust local strains in nearly the same manner that the great rift adjusts the regional differential horizontal strain. The southwest side of the San Andreas rift and its small replicas move relatively northwestward, and the northeast side relatively southeastward. It is to be observed, however, that the relative movement is necessarily reversed along the contact of the triangle with the buffer blocks, this causing the rotation and *en échelon* arrangement of folds in southern Ventura Basin to be the reverse of that prevailing in other parts of the coastal region.

Because the San Andreas rift is a regional feature which relieves strain in a much larger territory than the area of the triangle, its horizontal throw is considerably more than the distance which the triangle as a whole has moved westward.

In 1927 the writer computed, from the relation of Miocene sediments in the Caliente deep southwest of the great rift to those in the San Joaquin deep northeast of the rift, that there has been 24+ miles of horizontal throw along the San Andreas at that locality since the Miocene.[2] He has since discovered that Noble[3] had previously inferred 24 miles of post-Miocene throw from similar offsetting farther southeast. That Noble and the writer arrived at substantially the same conclusion though working in different areas and each unaware of the other's ideas,

[1] P. F. Kerr and H. G. Schenck, "Significance of the Matilija Overturn," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), p. 1101.

[2] J. E. Eaton, "Notes on the Principle and Theory of Isostasy," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 12 (December, 1928), p. 1165.

[3] L. F. Noble, "The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California," *Carnegie Inst. of Washington Year Book 25* (1925-26), p. 420.

seems worth mentioning. Drainage lines are offset along the rift. From these, Buwalda[1] has inferred as much as 5,400 feet of horizontal throw in very late times.

The San Andreas rift is a shattered zone a mile wide near its center, and narrower toward the ends, composed of long, parallel slivers separated by faults. A differential rising and falling of adjacent slivers locally ponds the drainage and results in a line of small, saline lakes. The slivers commonly expose rocks of different kinds and ages, partly because of local vertical movement between them, and partly because of horizontal offsetting. The amount of vertical throw differs greatly along the rift, being here little, and there as much as 5 miles. It scissors from side to side, being merely incidental to the greater horizontal movement. The horizontal throw is distributed in steps among several closely spaced parallel slivers, a few of which commonly show more recent activity than the others. Individual fractures branch from the rift at low angles, their throw commonly decreasing in short distances as they diverge from the main line of adjustment.

The deep-seated master shear of the San Andreas is probably single. The closely spaced parallel fractures which appear on the surface have seemingly resulted from the enormous resistance to slippage which causes the surface to fracture in long, narrow strips among which the total horizontal throw is divided. On Figure 8 (upper part) several of these parallel slivers are apparent.

The San Andreas rift is not expressed in the pre-Pliocene paleogeography of California as computed by the writer. All seas up to and including the Miocene crossed it widely with little or no reference to its line (Figs. 3 and 5, *A*). The rift appears abruptly and prominently in the early Pliocene, the seas after that time crossing it only on the northwest, and following it closely for several hundred miles (Figs. 5, *B*, *C*, and *D*, and 6, *A*). The first definite appearance of the San Andreas as a continuous fault coincides with the inception of perceptible compression and crustal shortening.

Local divisions of the rift seem to be older than the fault as a whole. That is, older, vertical faults are locally included in the rift. For example, much of the eastern edge of the Santa Lucia blocks is a fault line older than the San Andreas. The eastern edge of these and other crystalline blocks was the line of least resistance when the rift occurred; hence, the San Andreas incorporated one or more of the ancient boundary faults in its entire system (Fig. 4).

[1] J. P. Buwalda, before Geology-Paleontology Club, California Inst. Tech. (1930).

The San Andreas rift fault was almost a straight line in the early Pliocene. If the post-Miocene folds and thrusts southwest of it were smoothed out (prorating the continental shelf), the present curve in the fault would almost disappear and the line of rifting would be nearly straight. High initial curve is theoretically prohibited in a horizontal shear because the slightest deviation from a straight line enormously increases resistance to horizontal movement. A horizontal shear tends to take the straightest possible line at its inception.

If a line of rifting is bent after being established, the resulting increased resistance to horizontal slippage tends to cause thrusting at and near the bends. The feature that the main thrusting along the San Andreas rift is adjacent to its maximum bend shows horizontal movement without reference to the rift shape at inception, but the feature that this thrusting, which is post-Miocene, was minor in the Pliocene and increased more than tenfold in the Pleistocene, is evidence that the bend in the fault was increasing.

Definite evidence that the San Andreas rift was nearly a straight line in the early Pliocene and has since been bent westward is furnished by the fact that its deviation from a straight line at any point closely parallels the amount of post-Miocene crustal shortening southwest of it at that point. As a result: (1) because the curve in the rift is bowed southwest, the movement causing the curve was westward or southwestward; (2) the Sierra Nevada massif must have moved westward, or there would now be a void as much as 60 miles wide between massif and rift; (3) the Sierra Nevada massif being relatively unextended and incompressible, the crust in the Great Basin district must have moved westward, or there would now be a void 60 miles wide between district and massif.

The horizontal discrepancy of as much as 60 miles has been taken up by extending the crust in the Great Basin district from a maximum width of 380 miles to one of 440 miles, or a maximum extension of 16 per cent. The potential voids there have been filled by a collapse of the crust in the Great Basin in slices, much as when the support is removed from one end of a row of books and these fall sideways into an extended line with a normal fault between each two. The actual block-faulting was of course vastly more varied and complicated, there being no uniform datum plane or original shapes, but heterogeneous material which has resulted in all sizes, shapes, and kinds of grabens and directions of tilt (Fig. 2, section *AA*). The crustal collapse was more rapid than the cutting by desert streams; hence the drainage was ponded (Fig. 1).

CHRONOLOGY

The events leading to extension and collapse of the crust in the Great Basin district will now be discussed in the order of their occurrence.

MIOCENE

Miocene seas were widespread in California. Figure 5, *A*, shows the early upper Miocene (Monterey) paleogeography. Other Miocene seas were slightly less extensive, but were similar in aspect.

The first Miocene (Vaqueros) sea transgressed the area of the state rapidly and deposited as much as 1,000 feet of sub-massive basal sands, clays, and a little limestone. The sea hesitated, and then transgressed farther and laid down as much as 4,000 feet of late lower Miocene (Temblor) sand, clay, chert, and limestone. There was some volcanism near the close of the lower Miocene, but it was of comparatively small amount. The sea then retired from most of California.

The sea transgressed again widely in early upper Miocene (Monterey) time, and deposited as much as 5,000 feet of sand, chert, diatomite, volcanic ash, and limestone (Fig. 5, *A*). Three nearly equal members can commonly be recognized. The lower member, which coincided with the time of maximum volcanism in the Miocene, is of restricted areal extent and is locally represented by unconformity. Where present, it is composed partly of reddish sand and volcanic ash, and locally there are extensive basic flows and chemically precipitated limestone reefs. This lower member is a main oil reservoir at Kettleman Hills.[1] The middle member is chiefly chert, ash, and limestone. The upper division is largely soft diatomite and ash with some chert and limestone. The sea retreated at the close of Monterey time.

In the late Miocene (Santa Margarita) there was a third transgression locally as extensive as the second. Sediments then deposited to a thickness of 2,500 feet were chiefly sands, with a little chert, ash, and limestone. The Santa Margarita is essentially clastic, and indicates great changes to come. The Miocene closes in California with regional unconformity.

By the end of the Miocene the western bulwark was a mere shell covered by 30,000 feet of accumulated sediments through which isolated splinters of the basement rocks projected. It is particularly to be noted

[1]Regional stratigraphic studies of the writer indicate that much of the main oil horizon at Kettleman Hills is not Temblor in age, as has commonly been supposed, but is the overlying lower member of the Monterey. Paul P. Goudkoff (April 23, 1931) informs the writer that paleontology and petrography lead to the same conclusion.

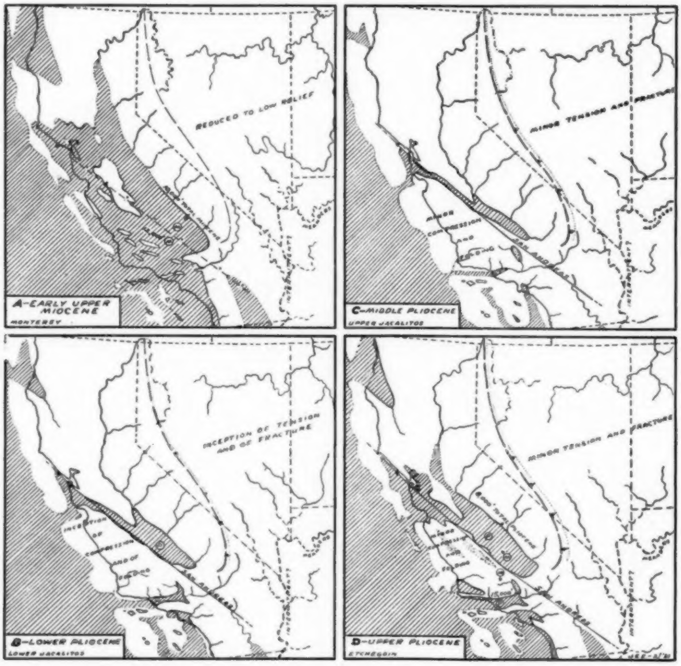

FIG. 5.—Paleogeographic glimpses of the later Tertiary. Epeiric seas lined, lakes dotted. The drainage is approximate.

A. The deposits of the quiet, land-locked, early upper Miocene sea are chiefly thin-bedded volcanic ash, diatomite, chert, and limestone. *B*. The deposits of the restricted lower Pliocene sea are clastic and coarse. *C*. Those of the extremely restricted middle Pliocene sea are clastic and very coarse. *D*. Those of the expansive upper Pliocene sea are clastic and least coarse.

The Miocene seas were broad, indicate little compression, and crossed the site of the San Andreas rift widely. The Pliocene seas were limited to narrow embayments, indicate moderate compression, and clearly reveal the San Andreas rift.

In the Pliocene, the transverse crease narrowed (compare with Figure 3), and as it narrowed it creased deeper with extreme rapidity. Miocene deeps (*M* and *M*) were in part squeezed out, and new deeps (*P* and *P*) were formed farther north and south. The massive Sierra Nevada block crept westward, the San Andreas rift began to buckle, and the crust in the Great Basin district commenced to fall apart.

that an ancient transverse crease had deepened steadily along the southern edge of the triangle in post-Cretaceous time, in effect cutting a notch in the crust, and causing a pronounced transverse zone of weakness (Figs. 3, 5, and 6, *A*).

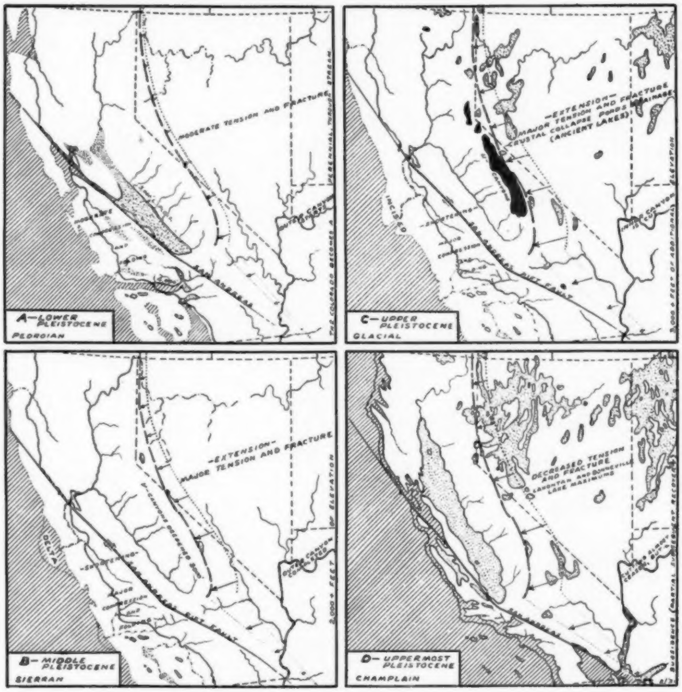

FIG. 6.—Paleogeographic glimpses of the Pleistocene. Epeiric seas lined, lakes dotted. The drainage is fairly accurate.

A. The lower Pleistocene (Pedroian) seas were restricted to the transverse crease and to small indentations in the state at and near the type San Pedro and type Merced. The marine invertebrate extinction is between 3 and 9 per cent. All deposits were coarsely clastic.

B. In middle Pleistocene (Sierran) time the continent rose, and the shelf became land. The Sierra Nevada massif moved westward more swiftly, compressing and shortening California. The Great Basin district followed, extended its crust, and fell apart. Much of coastal California was degraded several thousand feet, V-canyons were deepened 3,000 feet in Sierra Nevada granite, and the outer Grand Canyon was cut. The Golden Gate and other rivers built deltas.

C. In upper Pleistocene (Glacial) time maximum elevations and diastrophic intensities were attained. Coastal California was further degraded, three or more ice stages caused the Sierra Nevada canyons to become U-shaped, and the inner gorge of the Grand Canyon was cut. The deltas became emergent, were incised, and deep valleys were eroded on the edge of the abyss.

D. Highest Pleistocene (Champlain) time records a downwarp. The map illustrates the time of maximum depression, attained about 30,000 years ago. California has since recovered 1,300 feet or more with extreme rapidity.

The Sierra Nevada massif had lost its western support. Between it and the abyss lay a mass of geological jelly. The stage was set.

PLIOCENE

The first glimpse of the Pliocene map shows a changed aspect. Structure, sedimentation, and paleogeography are all new. It seems to be a different province (compare Figs. 5, *A* and *B*).

In contrast to the broad, comparatively flat basins of Miocene time, the early Pliocene basins were narrow, downfolding synclines separated by upfolding regions. Compression and shortening, though in small amount, had commenced. The continent had been elevated slightly, and pressure from the eastern highlands had overbalanced resistance in the western geosyncline. The Sierra Nevada massif was creeping toward the sea (Fig. 5, *B*, *C*, and *D*).

Because the deepest accumulation of plastic sediments was opposite its southern end and resistance there was, as a result, the least, the southern end of the Sierra Nevada moved fastest. Because the southwesterly directed pressure met northerly directed resistance from the massive buffer blocks, the triangle previously described moved westward (and relatively northwestward), causing a tremendous rotational strain between the Sierra Nevada massif and the abyss (Fig. 4). This strain was relieved by bringing into existence a great shear of adjustment—the San Andreas rift—along which differential horizontal movement occurred. When the details of the great rift are finally worked out, it will be found that its maximum horizontal throw is near its maximum bend, and that the throw dies northwest and southeast from this point. The San Andreas is the outgrowth of the Sierra Nevada, and the Great Basin district is its predecessor.

The lower Pliocene series of California represents a transgression of the sea (Fig. 5, *B*) during which fairly well bedded sands, brown and blue clays, and local gravels were deposited.

The middle Pliocene series (Fig. 5, *C*) represents a regressive phase locally resulting in unconformity, during which, due to the diminished capacity of the basins, chiefly coarse clastics were deposited.

In the upper Pliocene (Fig. 5, *D*) the sea transgressed again and reached its maximum extent in the epoch, laying down poorly bedded blue clays, sand, and gravel—chiefly clays.

The Pliocene series attains a thickness of 8,000 feet or more in parts of the large central basin of California. In the transverse crease (Ventura basin) along the southern edge of the triangle, as much as 15,450 feet of

strata were laid down, this constituting the thickest and most complete known marine record for the epoch.

Tension and block-faulting in the Great Basin district necessarily accompanied the westward movement of the Sierra Nevada massif in the Pliocene, for there could not have been a void 10 or 15 miles wide along the massif's eastern edge. Block-faulting doubtless began at the western edge of the Great Basin district, and extended east as the crust gave way in slices. The rate at which tension progressed eastward is unknown, but it seems probable that tension reached the Wasatch not later than the early Pleistocene. Tensional effects have presumably extended somewhat into the Rocky Mountain province. However, they would diminish rapidly east of the line of the Wasatch, for the thick plastic sediments forming the surface of the Rocky Mountain province would not block-fault as obviously as the more crystalline rocks of the Great Basin district, and would obscure such tensional expressions as exist below them in the crystalline basement. (Plastic areas resist tension, but are easily compressed. Crystalline areas resist compression, but are especially subject to tension.)

The various Pliocene movements discussed were only a faint prelude to greater movements to come.

PLEISTOCENE

As most geologists live in regions where only the upper (Glacial) division of the Pleistocene has left an obvious record, they are inclined to minimize lower, pre-Glacial parts of the epoch recorded in the great deeps. In parts of Europe and eastern North America, upper Pleistocene glacial drift may lie on horizontal Pliocene, or possibly on horizontal Paleozoic strata. The time interval between the drift and horizontal Paleozoic strata is known to be very large. Evidence being generally lacking, the time interval between the lowest drift and horizontal Pliocene beds has been assumed to be negligible. Workers in the shield-like areas step back and forth across a thin line of erosion between the lowest drift and the highest marine Pliocene, unaware that this thin line represents millions of years.

In California, the lower Pleistocene is represented by marine sediments, and the upper Pleistocene by three or more ice advances. Between these upper and lower divisions is recorded a middle division during which most of 6,000 feet of coastal degradation occurred, and canyons were deepened in granite 3,000 feet. If we estimate Glacial time as 1,000,000 years, the interval between the Glacial and the highest Plio-

cene approximates 4,000,000 years. This interval is that thin line of erosion at the base of the drift and coastal terraces which geologists who work in the flat parts of Europe and eastern North America have commonly underestimated.

The Pleistocene was a time of revolution. It began with a lower period of warning, progressed through a long middle period of slow preparation for frigidity, and culminated in a series of glacial stages. When viewed not as a cataclysm, but as a carefully prepared and inevitable phenomenon, the glaciation which occurred in upper Pleistocene time loses much of its mystery.

Lower Pleistocene (*Pedroian*).[1]—The Pleistocene begins in California with a pronounced acceleration of diastrophism accompanied by a revolutionary change in the invertebrate fauna. The seas oscillated, deposited 4,350 feet of coarse, marine- and brackish-water lower Pleistocene sediments in the transverse crease and 3,000 feet of coarse, brackish- and fresh-water deposits in the central basin (Fig. 6, *A*), and rapidly disappeared.

At the Pliocene-Pleistocene contact the marine invertebrate fauna changes abruptly to a recent aspect.[2] The faunal extinction is approximately 30 per cent in the upper Pliocene, decreases to 8 per cent 400 feet above the base of the Pleistocene, and slowly declines to 4 per cent through the succeeding 4,000 feet of lower Pleistocene sediments.

The basal 400 feet, more or less, of the lower Pleistocene series represents moderately cool water. The main body of sediment above this, approximately 4,000 feet in thickness, represents temperate and warm waters—chiefly warm. The warm-water lower Pleistocene contains a fauna so similar to Recent and semi-Recent faunas that paleontologists have commonly been unable to separate them, and have correlated truncated lower Pleistocene beds dipping 45° with almost Recent terraces, although the two series are separated by the erosion of 5,000 feet of strata (Fig. 7).

The temptation is to conclude *a priori* that the thin, basal, cool-water zone represents the first ice sheet recognized elsewhere. The evidence, however, precludes this. The 4,350 feet of lower Pleistocene

[1]The basal, transition sediments which were originally segregated merely to avoid dispute are so closely allied to the Pedroian (unquestioned lower Pleistocene) that the whole is here described under one heading.

[2]J. E. Eaton, "Divisions and Duration of the Pleistocene in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 2 (February, 1928), p. 117.

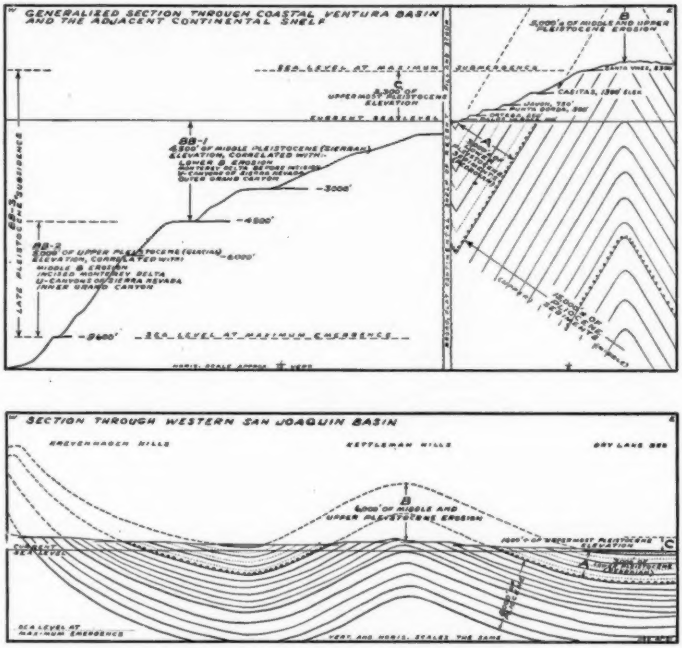

FIG. 7.—*Upper part.* The submarine terraces down to 4,500 feet below current sea-level are broad and clear. Those below this depth are evidenced, but are less clear. There are probably many small submarine terraces between the large terraces, but existent hydrographic soundings are too coarse to reveal them. The vertical scale for the continental shelf has necessarily been exaggerated approximately 12 times. The shelf is not nearly as steep as it appears in the drawing.

The fauna of the horizontal, almost Recent terraces and that of the ancient, truncated lower Pleistocene series which commonly dips from 30° to 60°, both represent warm waters and are so similar that paleontologists have generally been unable to separate them, although 5,000 feet of rocks was eroded in the interval between them.

Lower part. This part of the figure is drawn to scale. The territory illustrated was in the more protected part of a broad inland valley, several hundred miles by a devious route from the sea. Nevertheless, it was planed off in the middle and upper Pleistocene. Because the section is drawn to scale, the Champlain terracing, though shown, does not stand out clearly.

sediments locally present, though impressive, represent not more than the first 20 per cent of Pleistocene time, hence the 400 feet of cool-water deposits at the base represent not more than 2 per cent. This is much too small a percentage for an ice sheet of the magnitude commonly as-

signed to the first glaciation.[1] As Chamberlin and Salisbury[2] have said of a part of this basal zone, "it is not at all certain, or perhaps even probable, that the portion represented was any one of the glacial epochs."

The regional evidence brings out the true relations more strongly. In addition to the 4,000 feet of warm-water beds above this basal zone, there was 3,000 feet of subsequent canyon cutting in granite before the first of the three glaciations recorded in the Sierra Nevada occurred.

Although the regional relations prohibit the thin, basal, cool-water zone from representing any of the recognized glacial stages, these cooler strata at the base of a warm-water succession represent an important event. They record a first warning of distant frigidity to come— a warning probably repeated many times before the first great ice sheet invaded low latitudes.

Shortening in California and extension in the Great Basin district increased perceptibly in the lower Pleistocene, but the greater movement was to come.

Middle Pleistocene (Sierran).—The Quaternary revolution unleashed its strength in middle Pleistocene (Sierran) time. It closed all basins, drove the sea to the outer edge of the continental shelf, and raised California vertically 4,500 feet and the Great Basin district a somewhat similar amount (Figs. 6, *B*, and 7). It hesitated, and then, in upper Pleistocene (Glacial) time, raised the two regions vertically an additional 5,000 feet (Figs. 6, *C*, and 7). For simplicity, the evidence for vertical uplift during the two divisions (middle and upper Pleistocene) will be reviewed before resuming the chronologic discussion.

The evidence for at least 6,300 feet of vertical uplift of California during these two times seems inescapable. An additional 3,200 feet of uplift is indicated, but is not certain. In different parts of the state there was as much as 6,000 feet of Pleistocene degradation, dated by unmistakable lower Pleistocene invertebrate faunas (Fig. 7). Synclines were degraded as much as 5,000 feet,[3] and anticlines and monoclines as much as 8,000 feet.

Because the sediments involved were at sea-level in lower Pleistocene time, the degrading of down-folding synclines 5,000 feet means a

[1]See Table (Charles Schuchert, *op. cit.*, p. 654) after T. C. Chamberlin.

[2]T. C. Chamberlin and R. D. Salisbury, *Geology* (New York, 1906), Vol. 3, p. 495.

[3]W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924). See Pl. 2, sections *EE′* and *FF′*.

J. E. Eaton, "The By-Passing and Discontinuous Deposition of Sedimentary Materials," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), Fig. 10.

minimum of 5,000 feet of vertical uplift subsequent to lower Pleistocene time. Because the synclines mentioned are still near base-level of erosion after a minimum of 1,300 feet of almost Recent recovery in elevation, a minimum of 6,300 feet of vertical uplift occurred. Because these synclines were degraded at points 100 miles or more above the mouths of the ancient rivers, an additional elevation to provide a working margin is involved. The degradation of anticlines and monoclines as much as 8,000 feet is corroborative, but is not positive evidence such as is furnished by the three preceding factors mentioned.

Areas not in the path of efficient Pleistocene streams formed ridges and elevated plains which escaped with comparatively little degradation, but all basins in the state through which main drainage lines passed reveal degradation on the order of that discussed. The minimum epeirogenic uplift of California in middle and upper Pleistocene times, as evidenced by erosion, was thus 6,300 feet, and to this must be added a working margin for the streams of unknown but probably considerable amount.

Examining the adjacent continental shelf, we find submarine terraces and drowned valleys extending to depths 9,600 feet below current sea-level. Those down to 4,500 feet are unmistakable. Those below this depth are less clear because cut on a steeper slope (Fig. 7).

During the first stage of elevation (Sierran), the Golden Gate river, flowing southward through the old sea-way, deposited an extensive delta (Fig. 6, *B*). During the second stage, of increased elevation (Glacial), this delta was bisected by the river (Figs. 1 and 6, *C*). Gilbert[1] early recognized that

> An emerged shoreline is subjected to slow destruction by atmospheric agencies. Only the delta is rapidly attacked, and that is merely divided into two parts by the stream which formed it.

Turning to Colorado River, we find the two stages of vertical uplift represented by the two stages of the Grand Canyon.

The Colorado plateau has been saved from collapse by the feature that the buffer blocks in the coastal region opposite it have permitted only a minimum of westward movement to occur along the line between. Hence, block-faulting and crustal collapse have not extended as far inland there as they have farther north and south. The Grand Canyon has resulted from the circumstance that during the epeirogenic uplift of the continent in Pleistocene time the crust west of the Colorado plateau collapsed, but the plateau itself did not. The bed of the lower

[1] G. K. Gilbert, "The Topographic Features of Lake Shores," *U. S. Geol. Survey Ann. Rept. 5* (1885), p. 110.

river in the collapsed western area being let down approximately 5,000 feet, the middle river in the uncollapsed eastern area was forced to sink its channel an equal amount to the new level.

As the crust collapses on the west, Colorado River cuts down through the plateau. The river has partly attained grade from the mouth of the Grand Canyon at Grand Wash Cliffs eastward to the mouth of the Little Colorado, is out of balance from that place to Lee's Ferry, and has not had time to cut deeply beyond this point. The tributaries invariably illustrate the general principle.[1] The Grand Canyon thus represents the result of rapid cutting because of the tendency of the middle Colorado River to lower its bed to the level of the sunken bed of the lower river.

Because the crustal collapse west of the Colorado plateau could not have been appreciable, according to the causal events, before the Pleistocene, all of the Grand Canyon has resulted from Pleistocene cutting. Blackwelder's[2] discovery that the lower river did not exist in the Pliocene is more concise evidence to the same effect.

The two stages of Grand Canyon cutting, approximately 2,000 and 3,000 feet respectively, are correlative with the two stages of Pleistocene uplift in California. The broad outer canyon is thus middle Pleistocene (Sierran), and the steep inner gorge upper Pleistocene (Glacial), in age. The inception and cutting of a canyon 5,000 feet deep through a province in Pleistocene time is evidence of Pleistocene uplift of at least that amount.

Major premises of LeConte, Spencer, and McGee regarding continental uplift and erosion are corroborated by the minimum uplift of western North America of 6,300 feet in the Pleistocene. Any of four features: (1) the degradation in California, (2) the submarine terraces and drowned valleys on the continental shelf, (3) the incised Monterey delta, or (4) the cutting of the Grand Canyon, is sufficient to establish major uplift. All four clearly occurred contemporaneously, and three of them as clearly took place in two stages, the second stage recording nearly twice the height attained in the first. These four lines of evidence can not very well all be accidental, nor can their mutual agreement in time and amounts very well be a coincidence.

[1]Consult the Topographic Map of Arizona, U. S. Geol. Survey (1923), noticing particularly that the mouth of the Grand Canyon coincides with the boundary between the two structural provinces, and that Colorado River is cutting back from this boundary.

[2]Eliot Blackwelder, *op. cit.*

McGee[1] long ago recognized the great interval of erosion in the Mississippi Valley, and estimated[2] it to have ranged from 5,000,000 to 10,000,000 years in length. Spencer[3] has described the uplift as recorded by the continental shelves. LeConte[4] added the evidence of the Sierra Nevada, and summarized the whole. The greater interval described by these pioneers is represented in the thin line of erosion at the base of the drift in the shield-like regions of Europe and eastern North America.

The first stage of vertical uplift, approximately 4,500 feet in California and a similar amount inland, occurred in middle Pleistocene (Sierran) time. The writer estimates it, from its erosive work, to have been about 3,000,000 years in length. It deepened V-canyons in Sierra Nevada granite 3,000 feet, and with the exception of areas protected from streams, effected a more or less sheet-like degradation of coastal California of similar amount. Turbulent central rivers, coalescing and flowing through the Golden Gate, laid down a large delta off the central coast (Fig. 6, *B*).

The general continental uplift considerably increased the difference in elevation between the land and the abyss. The difference in elevation between the surface of the Great Basin district and the abyssal *basement*, approximately 3 miles in the early Cretaceous and 7 miles in the late Pliocene, had increased to 8 miles in the middle Pleistocene.

Faster, ever faster, and tilting as it went, the Sierra Nevada massif moved toward the sea. In its path the crystalline rocks shattered, and 30,000 feet of sediments crumpled (Fig. 2, section *BB*).

As the Sierra Nevada moved west, the epeirogenically uplifted Great Basin district followed; its crust was stretched and fell apart. The interior, desert drainage began to pond, for central parts collapsed faster than the rim. As the crust collapsed west of the Colorado plateau, the middle Colorado River, in re-establishing its grade, slowly cut the outer Grand Canyon.

Upper Pleistocene (*Glacial*).—The second stage of uplift approximately doubled the elevation of the continent, California being raised vertically an additional 5,000 feet, and provinces farther east a somewhat

[1] W J McGee, "The Lafayette Formation," *U. S. Geol. Survey Ann. Rept. 12*, Pt. 1 (1891).

[2] *Idem*, "Note on the Age of the Earth," *Science*, Vol. 21 (1893), p. 309.

[3] J. W. Spencer, "Reconstruction of the Antillean Continent," *Bull. Geol. Soc. Amer.*, Vol. 6 (1895); "Submarine Valleys off the American Coast and in the North Atlantic," *ibid.*, Vol. 14 (1903).

[4] Joseph LeConte, "The Ozarkian [Sierran] and its Significance in Theoretical Geology," *Jour. Geol.*, Vol. 7 (1899).

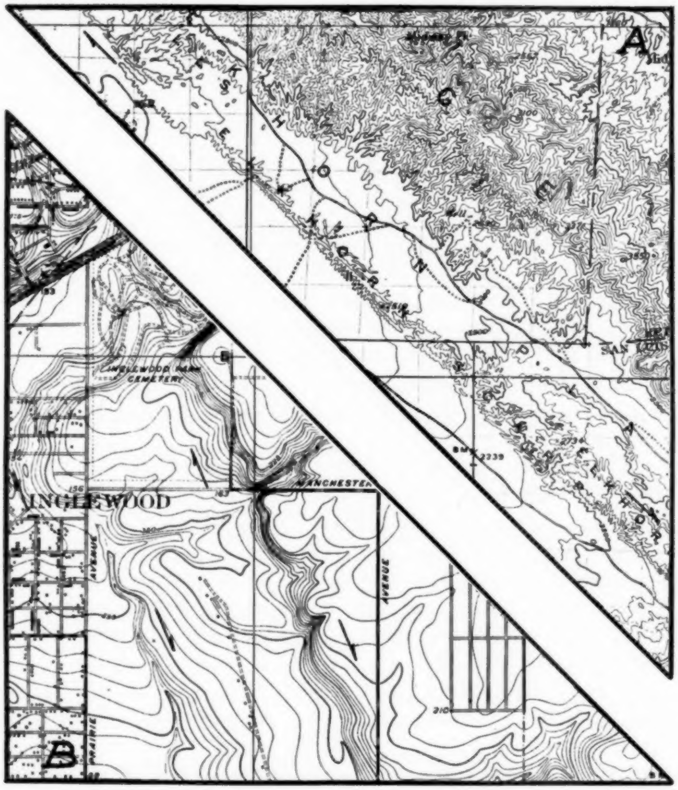

FIG. 8.—*A*. San Andreas rift in the McKittrick Quadrangle. Contour interval, 100 feet. The post-Miocene horizontal throw is here 24+ miles, or half again as long as the map. *B*. Newport-Beverly shear zone in Inglewood and Los Angeles cities, expressed at the surface by *en échelon* faults and folds. The faults deviate clockwise, and the folds counter-clockwise, from the deep-seated shear. Contour interval, 5 feet. The prominent scarp is that of the Potrero fault. Half a mile farther west is the almost obliterated trace of the parallel Inglewood fault which becomes prominent farther northwest. The post-Miocene horizontal throw along the zone is approximately 1 mile. Both topographic sheets are by the United States Geological Survey.

similar amount. As shown by two or more oscillations recorded by the lower Pleistocene marine sediments, and also by the many submarine terraces cut later, the Pleistocene uplifts occurred in a series of pulsations.

The second oscillating uplift here discussed was much swifter and shorter than the first, being approximately three times as rapid, but hav-

ing only a third the duration of the previous stage. If comparative durations are based on a minimum evaluation of erosion, the lower Pleistocene sedimentation occupied perhaps 1,000,000, the middle Pleistocene aqueous degradation 3,000,000, and the upper Pleistocene glaciation and erosion approximately 1,000,000 years.

The relative swiftness of uplift and relative short duration of the second stage of elevation compared with the first is attested by the same four lines of evidence: (1) the deeper submarine terraces on the continental shelf are cut on a much steeper slope than are the shallower ones, showing both swifter uplift and less erosion (Fig. 7), (2) the delta formed by the Golden Gate river during the first stage was much larger than that formed during and after incision (Fig. 1), (3) the pre-Glacial deepening of the Sierra Nevada canyons was much more impressive than the Glacial deepening,[1] and (4) the wide outer Grand Canyon represents a much slower and greater work of erosion than does the narrow inner gorge. In the long, first stage, Colorado River thoroughly established a new grade along most of its length, as did most other streams in the plateau province. In the shorter, second stage it had time to complete a new grade only as far back as the Little Colorado, and has as yet made hardly any headway beyond Lee's Ferry. Here again, in the four lines of evidence, is an agreement somewhat too close to be a coincidence.

Upper Pleistocene diastrophism in California and in the Great Basin district was an intensification of that of the middle Pleistocene, the considerably higher elevations of Glacial time partly offsetting the longer duration of the Sierran.

The shortening of California in Glacial time was so intense that many folds became overthrusts. The increased elevation caused the delta of the Golden Gate river to emerge and be incised (Fig. 1). Approximately the last thousand feet of degradation in the coastal region occurred in this division.

The high Sierra region was glaciated three times. Matthes[2] has discussed these glaciations, and has shown their relations to the long, canyon-cutting epoch which preceded them. The more important areas of upper Pleistocene glaciation are shown in black on Figure 6, *C*.

In the Great Basin district block-faulting and crustal collapse reached a maximum in the upper Pleistocene, for the greatly increased difference in elevation between continent and abyss caused the west-

[1] F. E. Matthes, "Geologic History of the Yosemite Valley," *U. S. Geol. Survey Prof. Paper 160* (1930).

[2] *Idem.*

ward movement to be most rapid at that time. The ponding of drainage was completed, the worn stump of the ancient continental divide near the middle separating the collapsed basin into two general watersheds. There were doubtless somewhat extensive lakes at times, but the still more extensive lakes of highest Pleistocene (Champlain) time have obscured these.

The crust west of the Colorado plateau collapsed more swiftly during the upper Pleistocene uplift, and Colorado River cut the inner gorge of the Grand Canyon with comparative rapidity.

Many geologists have hesitated to recognize major elevation of the continents in the Pleistocene. To this group the writer once belonged.[1] The evidence for major uplift, always full, now appears to be definite. The absence of visible marine sediments for times of maximum glaciation[2] shows the continents to have been widely emergent. Even in the great California deeps there is no marine record for the middle 80 per cent of the Pleistocene. The wide continental shelves of the earth, the littoral shells dredged from depths of thousands of feet, and the terrace series of the globe, extending from several hundred feet above current sea-level to several thousand feet below, all attest emergence. The drowned valleys and deltas of the earth, thousands of feet below current sea-level, furnish similar evidence. Different workers have recognized that the Pleistocene elevation and subsidence of the continental segments occurred in the form of oscillations, and further evidence of this has been given by the writer in this and a previous paper.

In Figure 9, based on the bathymetric map by Nansen,[3] the writer illustrates what happened if the Pleistocene elevation and subsidence of arctic lands was one-third the magnitude of that evidenced in temperate latitudes.

Figure 9, *A*, shows the continental shelf 200 meters lower than at present. It approximates the Pliocene. The arctic sea was then kept temperate by good marine circulation from equator to pole.

Figure 9, *B*, shows the shelf 200 meters higher than at present. It approximates middle Pleistocene (Sierran) time. The arctic waters

[1] J. E. Eaton, "Divisions and Duration of the Pleistocene in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 2 (February, 1928), p. 140.

[2] Several workers in the shield-like areas where relations are obscure seem to have correlated northern glacial drift with southern inter-glacial and post-glacial terraces. Geikie (A. Geikie, Text-Book of Geology, 1903, Vol. 2, p. 1301) has called attention to the possibilities for error in this respect.

[3] Fridtjof Nansen, *Amer. Geog. Soc. Spec. Pub.* 7 (1927), Pl. 1.

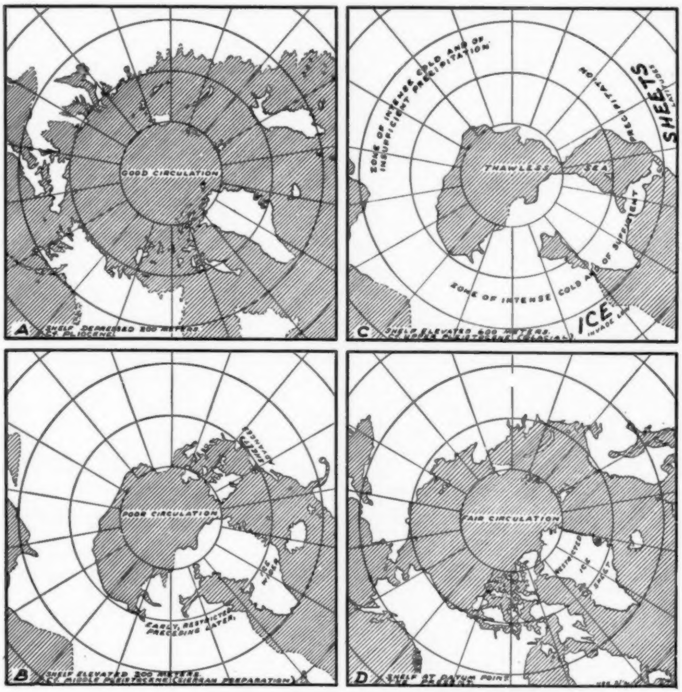

FIG. 9.—Seas lined. Illustrating how the earth is climatically zoned by restricting circulation between equator and pole.

A. In the Pliocene the continents had begun to oscillate slowly, but were in general lower than at present and there was good marine circulation from equator to pole.

B. In middle Pleistocene (Sierran) time the long first stage of oscillating uplift caused circulation from equator to pole to become poor. The drawing shows an upward trend during which there were theoretically ice sheets more extensive than at present, but much less extensive than the later, younger sheets which have been recognized.

C. In upper Pleistocene (Glacial) time the sharp second stage of oscillating uplift periodically isolated the arctic sea, intense cold spread radially from the thawless north, and the ice sheets rode far south over the elevated continents from certain centers of accumulation. Notice the land bridge or "detonator" between Europe and Greenland which closed on upward trends and cut off circulation.

D. At present, the "detonator" is open, circulation has been restored, and we live in an inter-glacial stage during which the ice sheet is restricted to Greenland.

were almost isolated, but there was still a slight connection with warmer seas. On upward oscillations of the continent there should have been ice sheets perhaps more extensive than the present ice sheet of Greenland, but much less extensive than the later sheets which extended into low latitudes and which have been recognized.

Figure 9, *C*, shows the shelf 600 meters higher than at present. It approximates an upward oscillation in upper Pleistocene (Glacial) time. There would be no circulation with warmer seas. The arctic sea would be thawless. From it, unceasing cold would extend in all directions. The ice would creep south—not the first ice sheet, but the first sheet to reach low latitudes and be recognized. Notice the narrow land bridge between Europe and Greenland. This we term the "detonator." It closed, or almost closed, on upward trends, circulation was cut off, and the ice sheets spread. It opened on downward trends, circulation became similar to that shown in Figure 9, *B*, and the arctic sea being warmed, the ice sheet dwindled.

Figure 9, *D*, shows the situation at present. The "detonator" is open. A hundred thousand years hence it will probably again close, or nearly close; the arctic sea will again become thawless, and intense cold will again creep south.

The theory outlined is doubtless not new. It supposes merely a redistribution of heat, the earth as a whole being no colder during a glacial stage than at other times, but merely zoned. During a glacial stage the snow line on equatorial mountains lowers with reference to their tops, but rises with reference to sea-level, for the continents are elevated a greater amount than the snow line changes. The antarctic, being highly elevated land at all times and perpetually surrounded by seas, should have been unceasingly glaciated during the Pleistocene, and possibly had a smaller ice cap in the Pliocene. Its ice sheet has expanded and contracted with crustal oscillation, but theoretically has not disappeared for millions of years. Because the seas surround it, the antarctic ice cap, perpetually chilled by the great heights at its center, can vary only within narrow limits. It is a significant feature, commonly overlooked, that there were no continental ice sheets in the southern hemisphere during the Pleistocene as in the north.

Given (1) the fact of an ice sheet in Greenland at present, (2) evidence of higher continental elevations in the Pleistocene, and (3) oscillation, a geologist completely unaware of Pleistocene ice sheets could deduce their existence, their advance, and their retreat.

Highest Pleistocene (*Champlain*).—California subsided during the late Glacial, presumably by stages, as indicated by submarine terracing

and smaller glaciations, but the sea did not certainly transgress the state until near the end of the latest downward oscillation, approximately 30,000 years ago. The sea then rapidly drowned the present valleys, and as rapidly retreated. This short, almost Recent invasion and withdrawal is recorded by a series of marine terraces now found at elevations ranging to 1,300 feet above current sea-level along the coast (Fig. 7, upper part). Terraces of more than 1,400 feet exist in the San Joaquin Valley, then inferentially a fresh-water lake, but whether these inland waters were fresh, brackish, or marine is unknown, as no one has yet investigated the flatter terracing (Fig. 7, lower part).

There is a 2,300-foot terrace along the coast which probably belongs to the Champlain series, but, as it possibly represents an earlier invasion of the sea, it is mentioned separately. The marine terraces up to 1,300 feet are so fresh that they can be only a few thousand years old. Several workers have described the fauna of the lowest or 100-foot terrace. It reveals warmer conditions than those which exist at present, and so closely resembles the fauna of the deformed lower Pleistocene beds that the two are confused by paleontologists although separated by as much as 5,000 feet of degradation (compare the structural relations in Figure 7, upper part).

The extreme rapidity of the Champlain marine invasion and retreat is shown by the fact that the sea did not have time to fill the valleys with sediment, but stayed only long enough to cut terraces and spread thin layers of gravel, sand, and fossil shells. This rapid oscillation shows that the Quaternary revolution continues to be active. At least 1,300 feet of elevation has taken place within the last 30,000 years. The known elevation in so short a period seems more remarkable to the writer than does the 9,500 feet of elevation and subsidence which occurred in the preceding 4,000,000 years. If the past rate of rise and fall corresponded with the more recent rate, California could have been uplifted to heights of 9,500 feet and back again 9 times during the middle and upper Pleistocene, or could have been raised and lowered 1,300 feet 66 times.

Despite this almost Recent recovery in elevation of at least 1,300 feet, California, the Sierra Nevada, and the Great Basin district are still relatively low compared with past elevations. The difference in elevation between the Sierra Nevada massif and the abyss is now less by many thousand feet than in the early upper Pleistocene. It is therefore inferred that the rate of western movement is much less than formerly. This inference from theory is supported by the feature that the overthrusts in the transverse crease, once very active, appear sluggish, and also by

erosion surfaces which indicate that the anticlines are growing more slowly at present than during much of the Pleistocene. Appreciable westward movement is still in progress, however, as shown by repeated movements along the San Andreas rift in historic time.

In the Great Basin district, highest Pleistocene (Champlain) time was characterised by the occurrence of extensive lakes (Fig. 6, *D*). The two largest of these, Lahontan and Bonneville, have been described by Russell,[1] Gilbert,[2] and others. The maximum of neither of these lakes could have resulted from melting ice, because the volume of water contained was many times the amount available from the melting of all glaciers within the watersheds. Jones[3] has viewed the Lake Lahontan maximum as an extremely late occurrence, and Antevs[4] is inclined to consider the high levels as fairly old. Whatever the precise dates may be, it seems certain that both lakes owe their maxima to a pluvial epoch. The writer here points out that the most pluvial conditions should have occurred at or near the time of lowest elevation (Fig. 6, *D*), dated by the California marine terraces (Fig. 7) as approximately 30,000 years ago.

Because tension is being transmitted from west to east across the Great Basin district, presumably from block to block, the eastern edge of the basin should lag appreciably behind the western edge in development. The amount of lag is at present unknown, and presents an interesting problem for study. The Wasatch, near the eastern edge, may lag 10,000 or 500,000 years diastrophically behind the western edge of the basin. The time of minimum activity, which occurred 30,000 years ago on the west, may not have reached the Wasatch, and the current stage of rejuvenation on the west will doubtless not reach the east for thousands of years.

Bearing on seismic susceptibility.—Because adjustment is being effected in California chiefly along certain major lines of differing magnitude, it is possible to calculate the relative seismic susceptibility of different areas. For example, the San Andreas rift, with locally 24 or more miles of horizontal throw since the Miocene (Fig. 8), is clearly the line of largest adjustment. The fault along the eastern side of the Sierra Nevada, with locally nearly 2 miles of vertical throw during the same

[1] I. C. Russell, "Geological History of Lake Lahontan," *U. S. Geol. Survey Ann. Rept. 3* (1883).

[2] G. K. Gilbert, "Lake Bonneville," *U. S. Geol. Survey Monogr. 1* (1890).

[3] J. Claude Jones, "The Geologic History of Lake Lahontan," *Carnegie Inst. of Washington Pub. 352* (1925).

[4] Ernst Antevs, "On the Pleistocene History of the Great Basin," *Carnegie Inst. of Washington Pub. 352* (1925).

period, ranks high, but may be inferior seismically to several faults with much larger horizontal throws.

In Figure 10 the writer has estimated the relative susceptibility of various areas. The map is based chiefly on structure, historic records being yet too short to be of much use in arriving at averages. The endeavor is made to present some geologic aspects as a contribution to the general problem. Although all the Great Basin district has, for lack of local evidence, been placed in class 3, some parts of it doubtless belong in class 2. Because a long delayed slip in a quiet area can be as great as one in a more active but more frequently adjusted area, it is to be emphasized that Figure 9 does not estimate the time, frequency, or magnitude of individual disturbances, but does emphasize relative susceptibility throughout long averages.

The maximum seismic susceptibility for California theoretically occurred in the lower Glacial, nearly a million years ago. If this maximum is designated as 100, the minimum, theoretically reached 30,000 years ago, may be estimated approximately at 30. Susceptibility has since increased slightly, and now, theoretically, is approximately 40. The theoretical rate for current seismic increase is nearly 1 per cent in 3,000 years. These percentages are approximate estimates based on the relative elevations which control the rate of westward movement.

Although less active than formerly, all parts of California and of the Great Basin district are definitely seismic areas. To build structures of brick, concrete, or stone, not reinforced, must ultimately result in destruction and death.

GENERAL APPLICATION

The discussion of lateral movement by gravity has so far been limited in this paper strictly to the Great Basin district and California, because these areas are best known. However, the phenomenon probably extends far south into Mexico, and north into Oregon and Washington. Perceptible westward movement has theoretically taken place at intervals along the highly elevated western coast of both North and South America, the deciding factor at any point evidently depending on whether the local bulwarks on the shelf between highlands and abyss have given way, and if so, to what extent.

The general process is not unique in these areas, but is occurring wherever highlands front abruptly on plastic lowlands. It is a relatively minor process, being subsequent and secondary to the major processes of mountain-making.

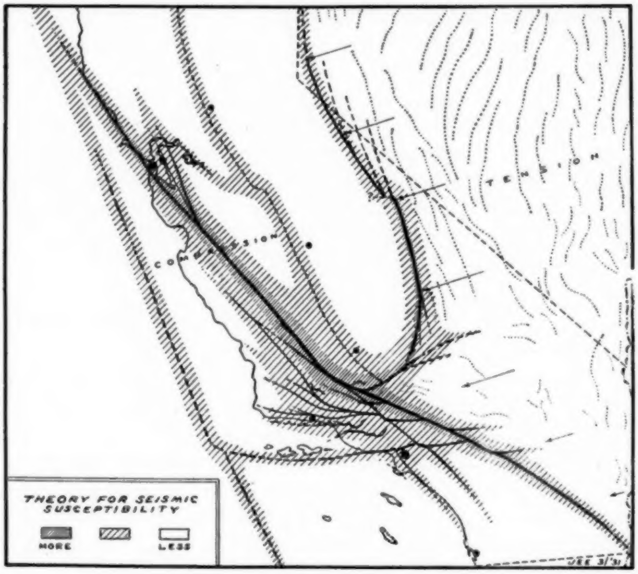

FIG. 10.—Some principal coastal faults are represented by solid, and Great Basin faults by dotted, lines. The relative closeness of shading shows the estimated relative adjustment and seismic susceptibility in California. The Great Basin district is unrated. The length of the arrows indicates the amount of coastal shortening, displacement of the San Andreas rift, and westward movement of the Sierra Nevada massif and its extensions in post-Miocene time.

The San Andreas rift, with 24 miles or more of post-Miocene horizontal throw, is the largest single line of adjustment and susceptibility. The southwestward movement of the Sierra Nevada is converted in part into northwestward movement on the coast. The San Andreas regionally relieves the rotational strain, this requiring 2 miles of horizontal throw for each 5 miles of southwestward movement, or approximately as 24 is to 60.

The adjustment in the compressed coastal region is effected chiefly by horizontal slippage; that in the extended Great Basin district is effected chiefly by compound movements along low-angle normal faults.

Diastrophism may be considered conveniently under three headings: primary, secondary, and tertiary. The lateral movement by gravity herein dealt with is in the tertiary class, and is commonly subordinate to the other classes.

The primary cause of diastrophism is unknown. It may be differential expansion and contraction of the globe, as some have thought. It may be increased and decreased rotation of the globe, as others have thought. There are other possibilities. We only know that at certain

times the continental segments rise, and, as the displaced shelf waters must go somewhere, oceanic segments relatively sink. Periodic rise and fall of the continents are known from the long, lost intervals between periods and eras for which there is no marine record on any continent, and during which nearly every species vanishes.

The secondary diastrophic feature (which results from the primary) is lateral compression of the continents between the oceanic segments. During this secondary stage, weak (geosynclinal) parts of the continents give way under tangential pressure, and fold and shorten. The continents as a whole are thereby shortened. The greater mountain systems of the earth—long, intensely crumpled systems such as the Rocky Mountain, Andes, and Appalachian chains—could seemingly be caused in no other way. In some such chains there is concentrated crustal shortening to be accounted for, ranging from 30 to 100 miles. This could not result from local vertical uplift, for such would cause extension instead of shortening. It could not result from a surface gravity flow such as that illustrated in this paper, because the mountain systems formed were higher than were adjacent provinces, and also because there seems to have been no equivalent extension of adjacent lands. To reflect on the tremendous shortening involved in a great folded system is to realize the mathematical necessity of there having been a net shortening of the continent; hence, either extension of the oceanic segments, contraction of the globe at a right angle to the strike of the system, or a distortion of the globe. (1) The amount of net shortening in a province is a measure of the amount which adjoining provinces have moved laterally. (2) The amount in which the net shortening in some provinces exceeds the net extension in other provinces, is the amount which a continent has been shortened.[1]

The tertiary diastrophic feature illustrated in this paper must nearly always be subsidiary to the secondary stage. Great mountain systems produced in the secondary stage by compression of the continents are so high above the continent as a whole that they are laterally out of balance, and tend at all times to move sideways. They can not move to any great extent when young because the adjoining crust is then competent, as evidenced by the feature that it transmitted the tangential pressure which folded the mountains. However, if a geosyncline later develops

[1]It is yet to be established that there is either net compression or net tension laterally in the crust of the globe as a whole, particularly as the net status of the oceanic segments is unknown. A shrinking globe would contribute to continental shortening, but shortening has been so vast in geologic time that extension of the heavy oceanic segments seems to be involved.

adjacent to the mountain system, the lateral support of the system is weakened, and the highlands may then move laterally by gravity and crush the adjacent geosyncline into a folded belt. A favorable condition for this is for the highlands to be broad, and the movement may be very large if the geosyncline lacks support on the side opposite the highlands, that is, if a high plateau fronts on the abyss as illustrated in this paper.

The subsidiary nature of the tertiary or gravity stage may be further illustrated by two examples. (1) The folded Coast Ranges of California produced by gravity movement of the Sierra Nevada are lower than the Sierra Nevada, and the Sierra Nevada as a whole is lower than the present, collapsed Great Basin. (The high eastern ridge of the Sierra Nevada is the tilted edge of a block whose average surface is not far above current sea-level.) The gravity flow in this example is subsidiary to the original mountain system of the Great Basin district which has been exerting lateral pressure since the mid-Mesozoic. (2) The plateau of Tibet, whatever its origin, is much too high above adjacent provinces to have been elevated by local surface gravity flow. It is now, however, theoretically moving outward under its own weight. Low, northern India is under compression,[1] the Himalaya is inferentially moving south, and the plateau of Tibet in the rear is theoretically in tension, is extending its crust, and is block-faulting in long slices. The Asiatic example is similar to the American, but is less advanced because of greater resistance on the south with resulting slower movement. The plateau of Tibet has block-faulted and collapsed sufficiently to pond its drainage locally, as may be observed in any good atlas, but seemingly it has not yet reached the stage attained by the Great Basin. Except for the frontal compression cited, the Asiatic features mentioned are inferred from analogy.

SUMMARY

The Great Basin district was a geosynclinal region in the Paleozoic and lower Mesozoic. It resisted the revolutions of those periods because it was then immature, that is, because other geosynclinal provinces were weaker during these revolutions and were pinched out first. In mid-Mesozoic time the geosyncline became mature, became in its turn the weak spot, and was pinched out to form a mighty mountain system of complicated folds and thrusts. It thus became a stiffened, resistant area. When in post-Cretaceous time the Coloradic geosyncline farther east

[1]Robert V. Anderson, "Tertiary Stratigraphy and Orogeny of the Northern Punjab," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927).

J. Marvin Weller, "The Cenozoic History of the Northwest Punjab," *Jour. Geol.*, Vol. 36 (1928).

became in turn the weak spot, the Great Basin district formed one of the buffers between which that area was crushed. The district was degraded, in the Cretaceous and early Tertiary, to a region of low relief. By Pliocene time the Pacific province had become the weak spot, and the Great Basin district began to move toward it. In the Pleistocene the continent was highly elevated, and there being locally no surface support west of the Pacific geosyncline, but only the abyss, the Sierra Nevada massif moved far westward under gravity. The Great Basin district followed, and, in attempting to extend its crust, block-faulted in long slices, collapsed, and ponded its drainage.

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HOBBS FIELD, LEA COUNTY, NEW MEXICO[1]

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ABSTRACT

The Hobbs field is near the southwestern rim of the Llano Estacado. Structure can not be mapped at the surface; the field was discovered by geophysical surveys. The producing structure is an elongate dome. The oil and gas reservoirs are members of that Permian system which occupies the Permian basin of West Texas and southeastern New Mexico. The main reservoir is a porous, light-colored limestone about 200 feet thick. The pressure in this reservoir is more than 1,500 pounds per square inch at a depth of 4,150-4,200 feet. Beyond the limits of the oil pool the reservoir-rock contains water under corresponding pressure. Porosity (hence initial production) is related to structure, being greatest along the anticlinal crest, less on the flanks, least in wells off structure. Approximately one-third of the folding occurred shortly after the deposition of the main limestone reservoir and before salt deposition. Almost two-thirds occurred after salt deposition and was probably post-Triassic, certainly pre-Pliocene.

INTRODUCTION

A comprehensive theory of oil accumulation in the limestone reservoirs of the Permian basin must account for all the commercial pools and certainly must not overlook any of the major fields. As one of the latter, Hobbs field has several individual and noteworthy characteristics.

Recently, in West Texas, a steep dip, either west or east, has become almost a criterion for some geologists. The greatest porosity in the limestone, consequently the largest oil wells, are expected along the steep dip. Down structure are edge wells and bottom water; up structure the flattening of the dip coincides with lean areas caused by scant porosity. Hobbs field, however, occurs on a somewhat symmetrical "closed"[4] anticline with the largest wells generally along the crest of the structure.

Much has been affirmed about the occurrence of oil at unconformities. According to a current hypothesis, which has considerable evidence

[1]Read before the Association at the San Antonio meeting, March 21, 1931. Manuscript received, June 10, 1931.

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[3]Resident geologist and petroleum engineer, The Midwest Refining Company.

[4]An anticlinal closure or elongate dome; not a closed fold of the structural geology textbooks.

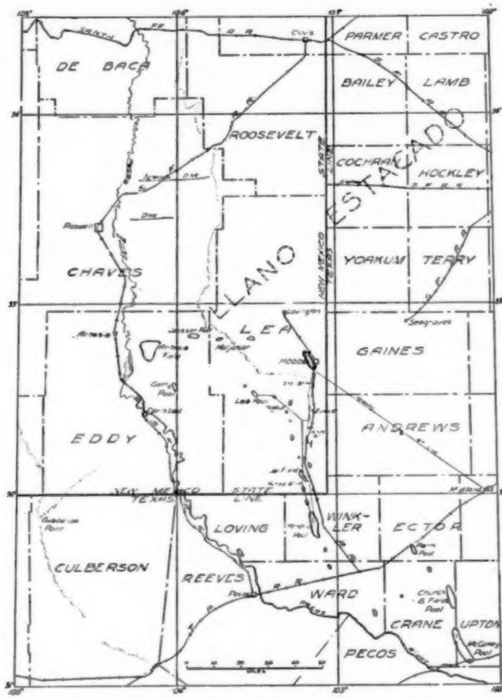

FIG. 1.—Geographic situation of Hobbs field.

in the Permian basin to commend it, the productive pores, cavities, and other openings in important limestone reservoirs of oil are formed in otherwise dense limestone by local uplift above the level of the sea and exposure to the effects of subaerial erosion and vadose water. To the more zealous proponents of this explanation a marine limestone formation that remains beneath the sea after deposition, represents almost a fullness of matter in space, an approximate plenum, which is effectively sealed by subsequent deposition of impervious conformable beds. They deny that such a limestone can possibly contain openings large enough or continuous enough to feed any considerable quantities of gas, oil, or water into a drill-hole. Subsurface evidence in West Texas oil fields, interpreted by some geologists as denoting lateral irregularities of subaqueous deposition, is construed by them to denote unconformities of a higher order,

involving ancient truncated faults, or Permian sea cliffs and island ravines, and other such marked forms of erosion in the open air. No pronounced features of that sort occur at Hobbs.

The present discussion of Hobbs field may well record a few data pertinent to the subject of oil accumulation in the Permian basin. Grateful acknowledgment is due Neil H. Wills for geologic ideas and for various kinds of assistance in the preparation of this article. The field is described as of March 31, 1931, and subsequent data, where mentioned, are relegated to footnotes.

HISTORY

Four and a half years ago a magnetometer survey by W. H. Denning and C. A. Weintz caused The Midwest Refining Company to purchase leases in the vicinity of Hobbs store and led to further prospecting with torsion balances. The gravity results encouraged the company to acquire more leases and to drill a test well on the "geophysical structure." The acquisition of the leases and the location and drilling of the discovery well were brought about mainly by the recommendations of R. Clare Coffin,[1] based on his own interpretations of the geophysical data.

On October 12, 1927, the discovery well (Fig. 2), The Midwest Refining Company's State No. 1 in the northeast corner of Sec. 9, T. 19 S., R. 38 E., was spudded in. The drill disclosed the oil in the "White lime" on June 13, 1928, at 4,065 feet. On November 8, 1928, the hole was 4,220 feet deep, where, having penetrated all the oil-bearing beds, it reached a little bottom water. The well flowed by heads, and during a six weeks' testing at this depth the average production was 700 barrels of oil daily.

The first exploration was on the south, where several oil wells and two dry holes were drilled, all structurally lower than the discovery well. The initial daily production of each was 1,000 barrels or less.

Obliged by government regulations to drill on the Bowers permit, the Humble Oil and Refining Company spudded in its Bowers No. 1, 3 miles northwest of the discovery, on June 10, 1929. The Bowers No. 1 disclosed the "Top anhydrite" and "Brown lime" markers approximately 100 feet higher than in the discovery well, and in August, 1929, reached considerable oil in a new "pay," the "Bowers sand." It also disclosed the big gas "pay." After the gas was cemented off, the well penetrated the "White lime" and was completed in the latter part of January, 1930. The initial hourly gauges indicated that the Bowers

[1]Chief geologist, The Midwest Refining Company, Denver, Colorado.

No. 1 could produce almost 10,000 barrels of oil daily, and these gauges were later substantiated when it did produce 7,275 barrels a day as an average during a period of 23 days.

The success of the Bowers No. 1 started the rapid development at Hobbs. Several wells were soon being drilled, but with no assurance of an outlet for oil except by hauling it out on trucks. The beginning of actual construction on a railroad and acknowledgment of definite plans for three pipe lines gave added stimulus to development. The Texas and New Mexico Railroad, a branch of the Texas and Pacific, was extended northward from Winkler County, Texas, reaching Hobbs in April, 1930. The Humble pipe line carried the first oil from Hobbs during the early part of May, 1930.

Three large oil wells were brought in during June, 1930, the first to be completed on the structurally higher, northwest part of the Hobbs structure subsequent to the Humble's discovery. These proved to be as productive as the Bowers No. 1.

In July the Atlantic and Shell pipe lines were completed and began to take oil. Proration of oil production went into effect on July 16, 1930, preceding which time the Hobbs field had produced less than 1,250,000 barrels of oil. On that date 26 oil wells were producing: 16 small wells in the southern end of the field and 10 large wells on the north. Drilling operations were actually begun or ready to begin on approximately 65 additional locations.

Since the completion of the three pipe lines the daily production of the Hobbs field has varied between 29,867 and 35,000 barrels of crude oil; that is, the average production has been slightly less than 1,000,000 barrels a month. Hobbs oil flows through the Hobbs pipe lines into the trunk lines of West Texas. The total production of the Hobbs field is limited by the trunk line demand. Proration thus determines not the amount but only the distribution of that limited total production.

On March 31, 1931, the Hobbs field contained one well being drilled and 143 oil wells; of the latter, 140 were actually productive, and 3 were temporarily shut in. The total production to that date was 9,591,736 barrels of oil, an average of 67,100 barrels per well. The average daily production per well was approximately 225 barrels.[1]

Initial production of oil from all wells at Hobbs is almost invariably large. One-hour gauges indicate that most of the wells can yield more

[1]May 31, 1931: 1 well being drilled; 143 oil wells; 138 productive wells; 5 temporarily shut in; total production to date, 11,724,293 barrels of oil; average total per well, 82,150 barrels; total daily production of field, 37,040 barrels.

than 5,000 barrels of oil a day each (Fig. 9), and that each of several can yield more than 20,000 barrels daily.

The calculated potential daily production from each well is 24 times the amount of oil actually produced during an open-flow test lasting one hour.[1] For purposes of proration, the Hobbs field is divided into 40-acre tracts and the potential daily production of each tract is reckoned as the *average* of the potentials of all wells on that 40-acre tract. The 140 productive wells at Hobbs are contained in 126 such tracts. The so-called potential daily production of the Hobbs field is the sum of 126 figures representing the average for each tract. Thus, on April 1, 1931, the "potential production" of the field was calculated to be 1,150,512 barrels of oil daily.

Two plants for the extraction of gasoline from natural gas have been erected in the field, namely, the Phillips plant and the Shell-Continental. Practically all the gas treated by these plants is produced with the oil, and practically all gas so produced is taken by one plant or the other. The average gas-oil ratio for the field during March, 1931, was approximately 900 cubic feet of gas per barrel of oil, and the individual gas-oil ratios of most of the wells did not vary much from this figure.[2] During March, 830,509,000 cubic feet of gas were treated; that is, approximately 27,000,000 cubic feet daily. After treatment, most of the residue gas is blown into the air. The field supplies Hobbs townsite with gas for domestic use, and a 4-inch pipe line carries gas 20 miles north to Lovington, New Mexico.

The rise and decline of the town of Hobbs has been rapid even for an oil-field town. When the discovery well was being drilled Hobbs consisted of two buildings, a school-house and a store facing each other across a country road. The very gradual influx of population subsequent to the initial discovery of oil became a rush after the completion of the Humble's Bowers No. 1. Besides the usual boomers, the news brought many of the miscellaneous unemployed, of whom there were large numbers throughout the country in the spring of 1930. In the late summer and fall of that year, when the drilling campaign was at its height, the population of Hobbs exceeded 10,000, making it after Albuquerque probably the largest city in New Mexico. However, the wells are wide spaced, and though there was extraordinary success in finding oil, the

[1]More recently these "potentials" are determined from curves prepared by a committee of engineers.

[2]Several structurally high wells have recently shown excess gas. The increase of gas is supposed to be due to "gas caps" that are forming locally and spreading (June 1, 1931).

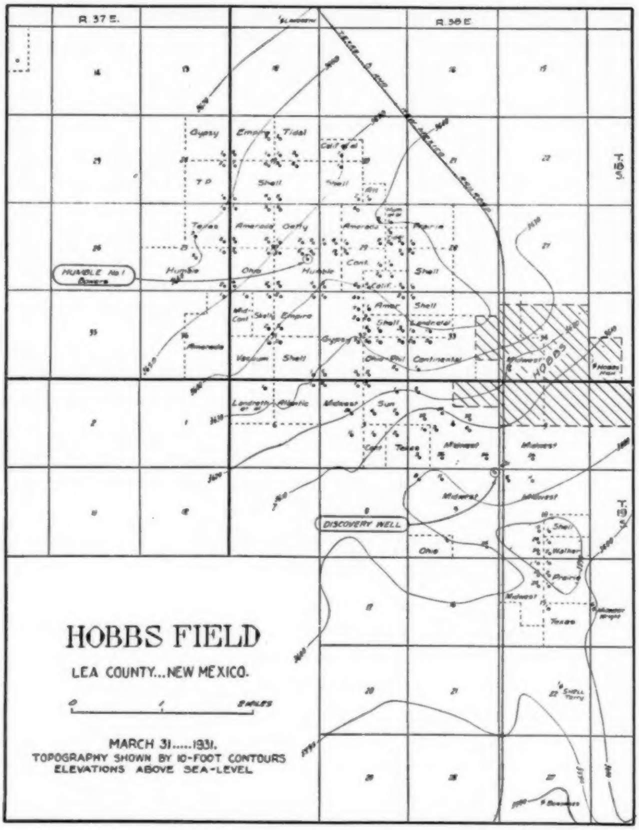

FIG. 2.—Topography and development of Hobbs field.

small outlet for it soon caused a virtual cessation of drilling. The northwest end of the Hobbs structure is not yet defined, nor is it completely defined on the northeast (Fig. 9). By February, 1931, the city of Hobbs had dwindled to a town of perhaps 1,000 or 1,500 inhabitants.

GEOGRAPHY AND AREAL GEOLOGY

The Hobbs field is on the high plains of West Texas and eastern New Mexico, the historic Llano Estacado, only a few miles from the

prominent scarp that forms the southwestern rim (Fig. 1). The topography at Hobbs is flat (Fig. 2). It slopes regularly downward toward the southeast at the rate of about 10 feet to the mile, having no hills or ravines and only a few shallow depressions, which are characteristic of the Llano. A slight elevation occupies the central part of the field.

Structure can not be mapped at the surface. No outcrops occur near Hobbs except caliche, soil, and windblown sand. Sand dunes are not present in the field proper, and the mantle of soil over the tough caliche rock is generally thin or lacking. Consequently the cellars and slushpits are dug and the pipe lines laid with the expensive aid of dynamite. On account of caliche, the Hobbs area is not a farming country. Prior to the discovery of oil it was used chiefly for cattle grazing.

SUBSURFACE STRATIGRAPHY

The underground sequence of beds at Hobbs (Fig. 3) is described herein from the top downward in the order of penetration by the drill. The type section is composite, derived mainly from the microscopic examination of the cable-tool cuttings from the discovery well, but with refinements suggested by samples and cores from subsequent wells. The stated depths and thicknesses refer to the discovery well. In structurally lower wells the depths to all pre-Tertiary horizons are greater by reason of the thickening of Permian formations and of the probable presence of additional Triassic beds beneath the Tertiary blanket. In structurally higher wells the depths are correspondingly somewhat less, the minimum depths at Hobbs being approximately 100 feet less than in the discovery well.

TERTIARY

During late Tertiary time a great apron of fluviatile débris was spread eastward from the Rocky Mountains, concealing older beds. This extensive deposit has been carved by subsequent rivers into large remnants, the southernmost of which is the Llano Estacado, bounded on the north by the Canadian River Valley, on the west by the valley of the Pecos, and grading into the Edwards Plateau on the south. On the east its bold scarps are indented by the headwaters of central Texas streams.

At Hobbs, near the southwestern rim of the Llano, the Tertiary formation is approximately 170 feet thick, consisting of buff to pinkish sand. The upper 50 feet increases in calcium carbonate content toward the surface, finally grading upward into a flaggy surface limestone (caliche). At approximately 60 feet it contains an excellent potable

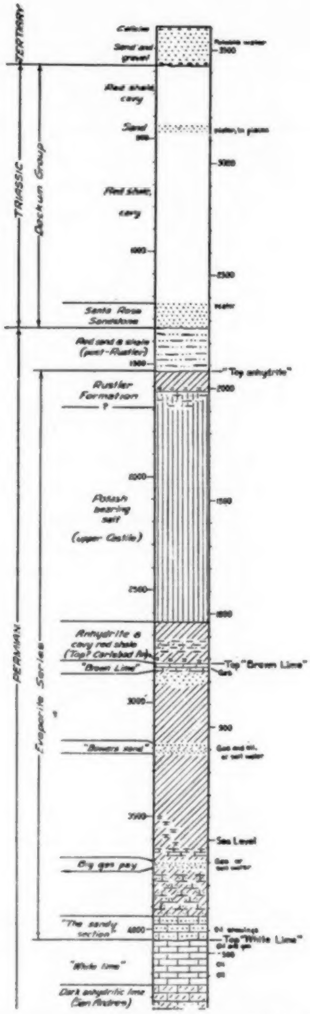

FIG. 3.—Columnar section, Hobbs field, Lea County, New Mexico. Depth and thickness correspond with discovery well in NE. ¼, Sec. 9, T. 19 S., R. 38 E. Systems, series, groups, formations, members, and depth in feet shown on left. Key horizons, fluids, and elevation above or below sea-level shown on right. Vertical lines, salt. Diagonal lines, anhydrite.

water in large quantities, supplying the field and town. The sporadic occurrence, at approximately 90 feet, of a bed of extremely hard chalcedony or opal (?) is the cause of the prevailing practice of spudding through the Tertiary beds before using rotary drilling methods. At or near the base of the formation, gravel beds are ordinarily present.

TRIASSIC (DOCKUM GROUP)

Shale.—In the discovery well a body of dark red shale and clay 1,060 feet thick extends from a depth of 170 feet to 1,230 feet. It is somewhat sandy near the top and near the base. From 440 to 470 feet occurs a 30-foot red sand, a lens-like member that seemed to be dry in the discovery well, though it yielded an appreciable amount of water which flowed into the diagonal offset, Capps No. 31. The gummy Dockum shale is very difficult to drill through with cable tools, but is easily and quickly drilled with rotary equipment. It caves into cable-tool holes and is penetrated only at the expense of much time or of several strings of casing, in many places both. This caused the introduction of rotary methods, although the finding of the "Big gas" caused their more extensive use. The discovery well was drilled in Dockum shale for several months before penetrating it.

Santa Rosa sandstone.—The basal formation of the Dockum group is the Santa Rosa sandstone, which is 110 feet thick and extends from 1,230 feet to 1,340 feet. It is water-bearing and consists mainly of calcareous, micaceous, red sandstone with some interbedded red shale. In many other localities the Santa Rosa is predominantly gray sandstone; therefore it is much easier to distinguish than at Hobbs.

PERMIAN

Post-Rustler Red-beds.—Beneath the Santa Rosa sandstone are almost 200 feet of sandy Red-beds. In the discovery well these extend from 340 feet to 1,533 feet. These Red-beds are classified as Permian because they are, in contrast to the Triassic beds, (1) more lithified; (2) the sand grains are very fine, angular, and of uniform size, not coarse-to-fine and subrounded-to-angular; (3) these beds beneath the Santa Rosa sandstone and above the Rustler anhydrite are readily correlated with Red-beds in similar position elsewhere in Lea and Eddy counties that contain small amounts of anhydrite or gypsum which relate them to the underlying Rustler and distinguish them from the overlying Dockum. In short, they have many of the characteristics of Permian Red-beds, which are well described by Adams.[1] Finally, in tracing the

[1] J. E. Adams, "Triassic of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 1052-54.

Santa Rosa sandstone northward and northwestward one discovers that it rests on successively older Permian formations, and in northwestern Guadalupe County, New Mexico, it lies only a few feet above the Glorieta sand, a Permian formation older than any yet penetrated at Hobbs.

"*Top anhydrite.*"—The "Top anhydrite" horizon is the contact between the post-Rustler Red-beds and the subjacent anhydrite of the Rustler formation. It is in general use at Hobbs in lieu of the "Top salt," which is an especially unsatisfactory marker in rotary wells. The "Top anhydrite" is the first key horizon encountered by the drill. Where it is found less than 2,000 feet above sea-level, it indicates that the well is probably too low structurally to produce oil or gas. This information is not obtainable from the Santa Rosa sandstone. Even if the thickness of that formation were constant and its members not lens-like, it would be useless as a key bed because it is irretrievably obscured by rotary-drilling methods.

Figure 4 shows the structure of the "Top anhydrite" with 50-foot contours, which outline the Hobbs fold as clearly as does the contouring on either the "Brown lime" or "White lime" horizons. Certain local irregularities appear in the "Top anhydrite" contours. These may be the result of any one of, or of various combinations of, four causes, namely: (1) inaccurate information, because the depth of the horizon is commonly determined from rotary samples or from drillers' logs; (2) lateral variations in deposition; (3) irregular folding caused by the underlying salt; (4) slight erosion of the anhydrite immediately after deposition. The last cause is as probable as any of the other three, for the sedimentary change from chemically precipitated anhydrite to mechanically deposited, sandy Red-beds is radical.

The interval between the base of the post-Rustler Red-beds and the top of the "White lime" is approximately 2,500 feet, and it is occupied chiefly by a series of light-colored evaporites and gray clastics. The amount of red material is minor. In general the more soluble evaporites are found near the top of the series and the less soluble toward the base; that is, salt predominates at the top, anhydrite in the middle, limestone near the base. The clastics have a random distribution.

All the limestones of this series, and all those penetrated in the subjacent "White lime" or beneath it are magnesian limestones.

Rustler formation.—In the discovery well the Rustler anhydrite extends from 1,533 to 1,620 feet. Samples from the lower part of this anhydrite contain a considerable admixture of limestone, corresponding with a distinct Rustler limestone member that occurs beneath the anhydrite in the region 25 miles or more southwest of Hobbs.

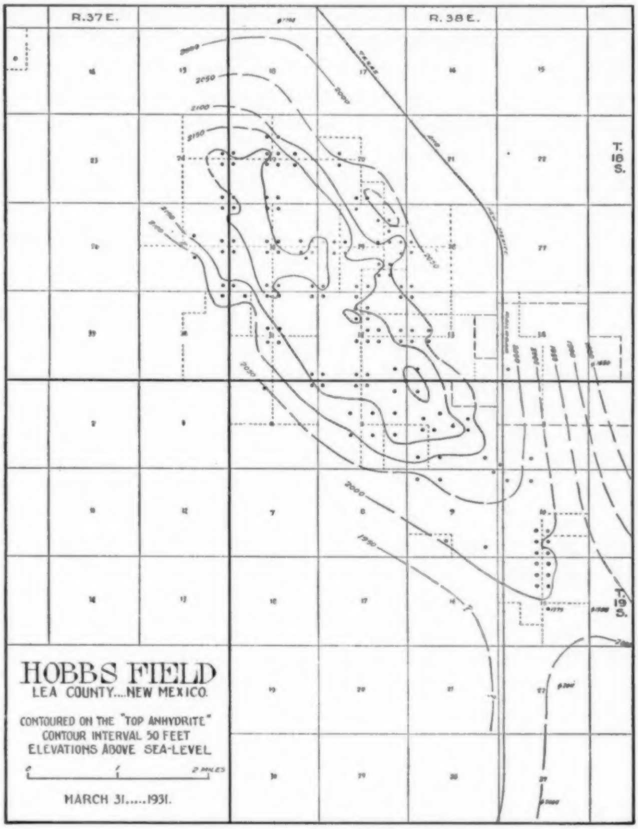

FIG. 4.—Structure of "Top anhydrite."

No doubt the saliferous red sandstones and sandy Red-beds directly beneath the Rustler anhydrite are correlative with the oldest, clastic members of the Rustler formation in the Pecos Valley of southern Eddy County, New Mexico. At Hobbs these beds interfinger with salt and are not definitely separable from the main underlying salt body.

Potash-bearing salt.—The main body of salt is 950-1,000 feet thick. It extends to 2,640 feet in depth in the discovery well. Thin anhydrite members and very thin layers of red sand and gray shale are interbedded

in the salt. Potash in the form of polyhalite is a plentiful constituent. This salt is the potash-bearing salt that occupies practically all southeastern New Mexico east of Pecos River, and extends into West Texas. In the Delaware basin it is the highest formation of the Castile series. Eighty miles southwest of Hobbs, near Carlsbad, where the salt is not nearly so deep, a potash mine is in operation.

So-called "air pockets" containing non-inflammable gas under high pressure are commonly found in the salt at Hobbs. The gas is quickly exhausted, but its first rush may blow cable tools up the hole or rotary mud fluid out and do considerable damage to drilling equipment.

Anhydrite and cavy red shale.—Beneath the main body of salt occurs 150 feet or more of anhydrite containing considerable red shale and a few stringers of salt. Farther southwest, at Getty, Lea, and Jal, a contemporaneous salt member occurs in this interval. It is there separated from the superjacent main salt body by a comparatively thin but widespread anhydrite bed, and is generally devoid of potash.

The red shale in the discovery well extends from 2,757 feet to 2,775 feet. When casing off the salt in cable-tool wells in the south end of the Hobbs field, it is essential to set the pipe below this red shale, because otherwise it caves readily into the hole and causes much subsequent trouble and delay.

"Brown lime" and subjacent beds.—Almost midway in the 2,500-foot series of evaporites occurs the "Brown lime" key bed. It is approximately 1,300 feet below the "Top anhydrite" and 1,200 feet above the "White lime." The salt lies above it, the anhydrite mainly below.

The first appearance of limestone beneath the cavy red shale in the discovery well occurs at 2,800 feet. From 2,800 to 2,825 feet the cuttings are predominantly anhydrite, but all contain some limestone. Subsequent coring in this 25-30-foot calcareous zone proves that the brownish gray or tan limestone occurs in different forms. Inch-thick beds of nearly pure limestone are found, and thin limestone laminae that bifurcate and reunite are common, with every gradation from them to tenuous films of limestone whose ramified intergrowth with the predominant anhydrite shows not the least semblance of horizontal bedding. The highest limestone of this zone is approximately correlative with the "Top lime" in the Lea, Eunice, and Jal areas, that is, with the top of the Carlsbad formation. Either the correlation is exact, or the youngest limestone at Hobbs is somewhat older than the highest Carlsbad. The difference is not great.

At 2,825 feet in the discovery well the drill entered a comparatively solid limestone, the top of which is the "Brown lime" key horizon. Unfortunately, no cores of the "Brown lime" proper have been taken. This member seems to be approximately 30 feet thick and to consist chiefly of grayish brown limestone with a minor amount of interbedded anhydrite. The "Brown lime" generally yields a small flow of inflammable gas from a porous bed about 10 feet below its top. The presence of this gas is of great aid in correctly determining the position of the "Brown lime" key horizon in wells from which samples are poor or

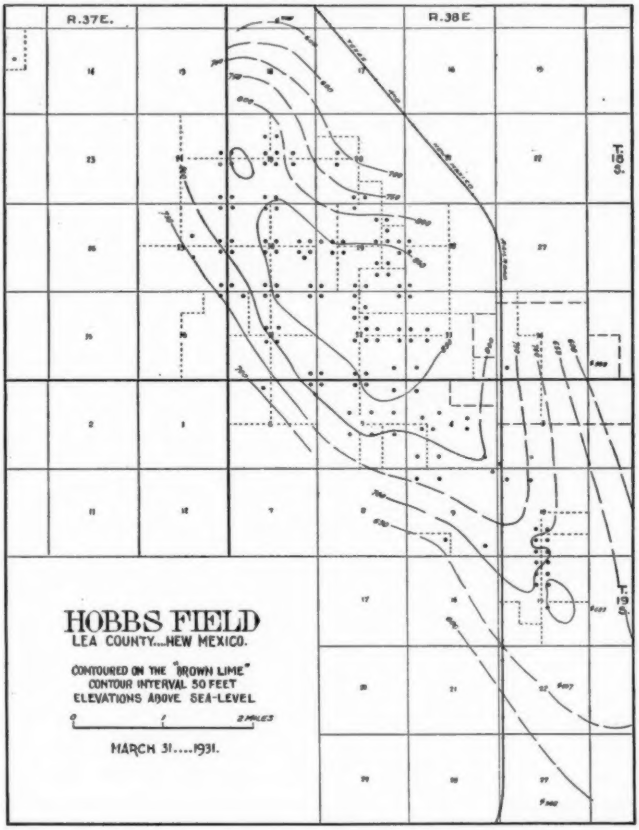

FIG. 5.—Structure of "Brown lime."

absent. The gas reservoir in the "Brown lime" may be considered the *highest "pay"* at Hobbs, although the amount of gas it yields is insufficient for any purpose except camp use.

Figure 5 shows the symmetrical, anticlinal structure of the "Brown lime" with 50-foot contours. The structural attitudes of the "Top anhydrite" and the "Brown lime" are much the same, but the "Brown lime" contours have fewer local irregularities.

Just beneath the "Brown lime" occurs a gray sand, which has yielded a showing of gas in a few wells. Thence downward to the "Bowers" sand the beds are predominantly anhydrite, containing little or no limestone, but some red and gray clastics, and in two wells a thin stringer of salt.

"Bowers sand" and subjacent beds.—The sand beds that occur between 3,175 and 3,220 feet yielded two separate showings of oil and gas in the discovery well. However, these were showings only, and this "Bowers sand" first gained distinctive recognition and a name when considerable oil and gas were discovered in the Humble's Bowers No. 1, as previously mentioned under HISTORY.

The reason for the two distinct showings in the "Bowers sand" is made plain by the following condensed description of cores from the Shell Petroleum Corporation's McKinley No. 1, SW. ¼, Sec. 19, T. 18 S., R. 38 E.

Overlying beds	*Thickness in Feet*
A. Anhydrite with streaks of limestone	11
B. Gray anhydritic sand	2
C. Anhydrite with streaks of limestone	6
"Bowers sand"	
D. CORE LOST (probably loosely cemented sand)	4
E. GRAY SAND	1
(D and E comprise upper productive member)	
F. Anhydrite	1
G. Gray sand	1½
H. Anhydrite and sand	½
I. Anhydrite, limestone, and red rock	11
J. Anhydrite, streaks of sand	1
K. Anhydrite and red rock, little limestone	5½
L. Sandy shale	½
M. Anhydrite, few streaks of limestone	9
N. CORE LOST (probably loosely cemented sand)	5
O. SANDY SHALE	8
P. CORE LOST (probably loosely cemented sand)	3
(N, O, and P comprise lower productive member)	
Total thickness of "Bowers sand"	51
Underlying beds	
Q. Anhydrite and sandy shale	7
R. Anhydrite and red rock	24

The "Bowers sand" is the *second "pay"* of the Hobbs field. From many wells on the crest of the structure considerable oil could be produced from this "pay," although none has been produced, excepting from a few during brief periods of testing. As the porous members of the "Bowers sand" are lens-like, it is not probable that all structurally high wells can be made productive. No oil or gas was noticed in the rotary returns from any of the eight wells in the central part of Sec. 19, T. 18 S., R. 38 E., while drilling through the "Bowers sand," excepting the Shell Petroleum Corporation's McKinley No. 5. Probably all potentially productive wells, besides several that are not productive in this "pay," lie within the area enclosed by the contour marked "−400" in Figure 8. The "Bowers sand" oil will probably be used at some future time.

During the last week of August, 1929, the Humble's Bowers No. 1 disclosed considerable oil in the "Bowers sand." When tested early in September the well produced 748 barrels of oil in 43½ hours. The average rate of production was therefore 413 barrels a day.

The Ohio-Phillips' State No. 1, SE. ¼, Sec. 32, T. 18 S., R. 38 E., produced 475 barrels of oil from the "Bowers sand" in 34 hours, or at an average rate of 335 barrels daily. The north offset, Shell's State No. 1A, NE. ¼, Sec. 32, produced 279 barrels in 18 hours, an average rate of 372 barrels daily.

The Midwest's Turner No. 29, SW. ¼, Sec. 34, T. 18 S., R. 38 E., flowed by heads from the "Bowers sand" every other day, each flow yielding approximately 200 barrels of oil. The approximate initial production from this well was therefore 100 barrels daily.

Gravity determinations of the oil from the "Bowers sand" vary from 37° to 40° A. P. I., and the oil has a paraffine base.

In some wells the flow of gas accompanying the production of oil from the "Bowers sand" has been reported as several million cubic feet. Probably these large flows should not be expected to continue.

The Midwest Refining Company's Byers No. 33, NE. ¼, Sec. 4, and State No. 8, NW. ¼, Sec. 4, T. 19 S., R. 38 E., produced respectively 70,000 and 105,000 cubic feet of gas per day from the "Bowers sand" and "Brown lime" together on continuous production for more than two months. Since March 19, 1931, the "Bowers sand" has been completely shut in, producing neither gas nor oil from any well in the field.

The casinghead pressure of the combined gases from the "Brown lime" and "Bowers sand" in the Amerada Petroleum Corporation's State No. 1A, NE. ¼, Sec. 32, T. 18 S., R. 38 E., was recorded as 1,400 pounds per square inch by a leaky gauge. Very probably some oil was

standing in the hole at the time, thereby further diminishing the recorded pressure. Possibly the pressure in the "Bowers sand" exceeds 1,400 pounds per square inch by as much as 100 or 200 pounds. To kill this well with water required a maximum pressure of 1,800 pounds per square inch in the Halliburton pumps.

In the structurally low, southern end of the Hobbs field, showings of oil and gas, or a little water, are commonly found in one or both of the productive members. Where "Bowers sand" water is present, it is the first beneath the Triassic; in other words, no water has yet been detected in drilling the 1,850 feet of beds between the Santa Rosa sandstone and the "Bowers sand." The limestone content of the "Bowers sand" is considerably increased in the southernmost part of the field.

Beneath the "Bowers sand" the beds are predominantly anhydrite with red and gray clastics and a thin stringer of salt at 3,280 feet in the discovery well. At 3,400 feet some limestone appeared in the anhydrite samples, and was nowhere lacking below this. From 3,545 to 3,675 feet a considerable access of darkish limestone showed in the cuttings.

"Big gas pay" and subjacent beds.—The Humble's Bowers No. 1 also disclosed the "Big gas." Beds equivalent to this "pay" probably occur at 3,700-3,730 feet in the discovery well, in which well, though yielding a slight showing of oil, they were not particularly noticed, nor did they attract particular attention in subsequent wells until the Bowers No. 1 disclosed the "Big gas" on October 15, 1929. The gas occurs chiefly in beds of sand. Herewith is a description of cores taken from the "Big gas pay" in the Shell Petroleum Corporation's McKinley No. 1, SW. 1/4, Sec. 19, T. 18 S., R. 38 E. The extent of the two zones that were reported as producing gas in this well is indicated by printing their component beds in capitals.

		Thickness in Feet
A.	Red rock, 80 per cent, anhydrite 20 per cent	2
B.	Limestone, some bentonitic shale	1½
C.	Anhydrite	5½
D.	LIMESTONE	1½
E.	SAND 80 per cent, ANHYDRITE 20 per cent	½
F.	ANHYDRITE 50 per cent, LIMESTONE 30 per cent, SANDY ANHYDRITE 20 per cent	1
G.	SANDY SHALE 80 per cent, ANHYDRITE 20 per cent	8
H.	Anhydrite 50 per cent, sandy shale 50 per cent	4½
I.	Anhydrite	3
J.	Anhydrite 90 per cent, sandy limestone 10 per cent	4½
K.	SAND	½
L.	LIMESTONE 50 per cent, ANHYDRITE 50 per cent	1½
M.	SANDY SHALE	½
N.	SANDY ANHYDRITE	½

	Thickness in Feet
O. SAND	½
P. ANHYDRITE 70 per cent, SANDY SHALE 30 per cent	½
Q. SAND 50 per cent, SANDY SHALE 50 per cent	2
R. Sand	2
S. Sandy shale 70 per cent, anhydrite 30 per cent	6
T. Anhydrite 60 per cent, red rock and sandy shale 20 per cent, limestone 20 per cent	6
U. Anhydrite 90 per cent, red rock 10 per cent	3
V. Anhydrite	2
W. Limestone	1
Total thickness of formation described	58
Total thickness of alleged upper pay zone (D to G)	11
Total thickness of beds between pay zones (H to J)	12
Total thickness of alleged lower pay zone (K to Q)	6
Thickness of interval D to Q	29

The big gas "pay" is the *third "pay"* of the Hobbs field. The rate of flow when gauged after blowing open for several days was 50,290,000 cubic feet daily. This gas did not quickly exhaust itself, as one might have expected it to do considering the kind of beds in which it occurs. The well blew open for nearly a month before the drillers succeeded in killing it, and in this time the flow decreased somewhat, but showed no signs of becoming exhausted.

Many subsequent wells have encountered the "Big gas." The total volume of gas that could be produced from this "pay" at Hobbs is great, but one could hardly expect the large initial flows to maintain themselves through long periods of concurrent production from many wells. None of this gas has been produced, excepting the comparatively small amounts wasted through drilling accidents. At present the "Big gas" is thoroughly mudded off or cemented in every Hobbs well that contains it.

The productive extent of the "Big gas" over the top of the Hobbs structure is much the same as the extent of the oil in the "Bowers sand," although somewhat more restricted. Examples are the Midwest's Byers No. 33, NE. ¼, Sec. 4, T. 19 S., R. 38 E., and the Midwest's Turner No. 29, SW. ¼, Sec. 34, T. 18 S., R. 38 E., both of which were oil wells in the "Bowers sand" but failed to find the "Big gas." In Byers No. 33 the "Big gas pay" at 3,720-3,725 feet yielded very salty water which rapidly rose 3,600 feet[1] in the hole to a height within approximately 100 feet of the surface. This head of saline water indicates a bottom-hole pressure of not less than 1,600 pounds per square inch.

During a test by the United States Geological Survey that lasted 5 hours and 25 minutes the casinghead pressure of the "Big gas" from the

[1]Amount reported by driller.

Humble's Bowers No. A2A, SE. ¼, Sec. 30, T. 18 S., R. 38 E., increased from 100 pounds per square inch when first shut in to 1,005 pounds at the termination of the test. By extending a graph of the rise in pressure, the government engineers estimated a rock pressure of 1,200 pounds. Probably this estimate is too low, for the oil from the "Bowers sand," which was not cased off, was probably collecting in the hole during the test. The depth of the well at that time was 3,720 feet.

Member B in the preceding core description contains bentonitic shale, which also occurs in the discovery and many other wells seemingly at the same horizon.

Beneath the "Big gas pay" occur anhydrite and limestone in nearly equal amounts interbedded with gray limy sandstone.

"*The sandy section.*"—From 3,945 to 4,045 feet in the discovery well occur 100 feet of beds locally known as "the sandy section," and composed of limy sandstone, limy shaly sandstone, limy shale, sandy limestone, limestone, and intermediate sediments variously interbedded. Chemically considered, "the sandy section" is predominantly calcium magnesium carbonate, but sand is the characteristic material. The sand grains are fine; probably their maximum size is 0.06 mm. Secondary veinlets of anhydrite occur, and pyrite is common.

The last appearance of anhydrite in beds subjacent to the "Big gas pay" coincides approximately with the top of "the sandy section." In regional work, however, correlations should not be made on the disappearance of anhydrite. Five miles west of Hobbs field, for example, in the National Securities' Linam No. 1, SW. ¼, Sec. 33, T. 18 S., R. 37 E., the entire 450 feet of beds that extend from above the "Big gas" down to the "White lime" are mainly limestone containing considerable interbedded sand, but no anhydrite. In the Eunice area 15 miles south of the Securities well, limestone predominates beneath the "Brown lime" and anhydrite is almost absent excepting in the highest 200 feet of the Carlsbad formation. Likewise at Hobbs the "Big gas" marks the lower limit of red material, but Red-beds occur stratigraphically much deeper in the area on the north and not nearly so deep on the south.

The sandstone members of "the sandy section" are non-porous. Some cores of limestone, however, have small pores containing oil. "The sandy section" in several wells has yielded considerable showings of oil (amounting in some to 10 or more barrels daily) but no noteworthy amounts of gas. It is common practice at Hobbs to set the oil string in the upper part or in the middle of "the sandy section" before drilling into the "White lime."

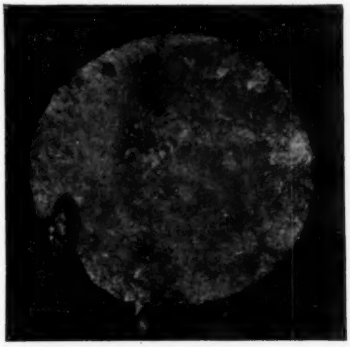

FIG. 6.—Core from base of "the sandy section." Photograph by D. L. Kessler; 0.8 natural size.

It is important to note that the shaly and sandy beds in the basal part of "the sandy section" contain angular fragments derived from the slight erosion of the highest member of the "White lime." The largest pieces are hardly more than an inch in diameter and are not common. The smaller limestone fragments are plentiful, but so small that the conglomeratic constitution of a specimen generally becomes apparent only on close inspection. Two of the larger pieces are readily seen in the photograph (Fig. 6) of a core from the lowest 3 feet (4,042-4,045) of "the sandy section" in the Atlantic Oil Producing Company's State No. 1, NE. 1/4, Sec. 6, T. 19 S., R. 38 E. The groundmass of this specimen also contains many smaller fragments.

"*White lime.*"—The structure of the top of the "White lime" is shown in Figure 8 with 25-foot contours. The folding is more accentuated than that of either the "Brown lime" or the "Top anhydrite." The "-550" contour on Figure 8 approximately outlines the lower limit of commercial production.

In contrast to the overlying "sandy section," the "White lime" is almost devoid of sand. Its top part is composed of dense gray pyritic limestone with a bluish tinge, which is not a reservoir rock but is the cap rock over the reservoir. Although small openings occur here and there even in this dense rock, they are sparse, and the limestone is characterized by its porcelaneous texture, subconchoidal fracture, and bluish color. It was the erosion of material of this sort that yielded the fragments found in the basal conglomeratic members of "the sandy section."

The "White lime" is the *fourth "pay"* and the main "pay" of the Hobbs field. After entirely penetrating "the sandy section" and drilling 1-30 feet—in most of the wells, 15-20 feet—of the bluish limestone, the drill encounters oil and gas in soft, very porous limestone or in an actual cavern. The threefold evidence of cavernous openings on the crest of the structure is fairly convincing.

1. Loss of returns is evidence of cavernous condition. In drilling ordinary rock with rotary tools, as much water, or mud fluid, returns to the surface as is pumped into the hole, and the fluid level in the slush pit remains fairly constant. When the porous beds beneath the dense bluish limestone are penetrated, some returns are lost and the fluid level of the slush pit subsides. High on structure, where caverns possibly exist, all returns may be lost so that none of the water pumped into the hole returns to the surface. In the Continental's State No. 1C, SE. ¼, Sec. 5, T. 19 S., R. 38 E., the driller reported a "four-foot cavity" at 4,040-4,044 feet, and this well while being drilled deeper consumed all the water from at least five water wells. The water was pumped in for several days and none of it returned to the surface during drilling; it came back later with the oil produced. In spite of such abuse the well subsequently flowed at the rate of 20,671 barrels a day during hourly gauges. The Midwest's State No. 8, NW. ¼, Sec. 4, T. 19 S., R. 38 E., a 23,548-barrel well, had a similar history. In a few early wells,[1] where no preparation was made for these conditions, drilling fluid was pumped into the hole with no returns until the return pit was quite exhausted, whereupon the oil and gas, out of control, forced the fluid back out of the hole and the well ran wild.

2. Rotary tools suddenly drill downward in some wells without any apparent resistance, or cable tools drop as into an open space. The Midwest's Byers No. 33, NE. ¼, Sec. 4, T. 19 S., R. 38 E., was drilled in with cable tools. After hard drilling through 15 feet of bluish limestone the tools suddenly dropped the full length of the stroke and swung free. The drillers, suspecting the truth, ran from the derrick floor, and a few moments later the top of the control head was blown off by a great rush of oil that shot over the crown block. When the well was again under control, hourly gauges indicated a daily rate of flow of 21,249 barrels.

3. A peculiar fragment was blown out during the testing of the Amerada's McKinley No. 4, NW. ¼, Sec. 30, T. 18 S., R. 38 E. It has

[1]Example: The Shell Petroleum Corporation's State No. 1A, NE. ¼, Sec. 32, T. 18 S., R. 38 E., 4,000-4,004 feet, June 4, 1930. Gauged potential after subsequent deepening, 5,347 barrels a day with 62,000,000 cubic feet of gas.

an oval cross section about 1 inch in diameter, is 2½ inches long, and tapers somewhat. The sides are fairly smooth and of weathered appearance, the ends are fresh and broken. It is internally banded. The banding is not smoothly oval like the cross section but is flattened toward rectangularity. The fragment appears to be a calcareous growth broken from the walls of a cave.

Beneath the dense bluish member and the top oil and gas occur more than 150 feet of light-colored limestone all more or less saturated with oil. Coring yields cores that bleed oil, but the West Texas maxim concerning limestone reservoirs that "a bleeding core never produces" is also true at Hobbs. The genuine reservoir beds are composed of such porous limestone that little or none of it is recovered by coring. Actual production is indicated in advance of testing by core loss and the loss of rotary returns. Such productive porous patches are found in the "White lime" at Hobbs beneath the top oil and gas, but ordinarily are not so prolific. The rule may be stated thus: if a well produces 10,000 barrels daily from the top of the "White lime," deepening will not increase it appreciably; if it produces only 200 or 300 barrels daily, deepening may treble its production. In the larger wells, which are drilled in with rotary tools, the pumping of drilling water into the top productive limestone for several days probably injures its productivity to an extent that more than discounts any gain from deeper porous beds. The smaller wells at the southern end of the field are drilled in with cable tools.

In this connection the history of the discovery well is interesting. It was drilled entirely with cable tools. Considerable showings were encountered in the base of "the sandy section" above the top of the "White lime" at 4,045 feet. The accompanying tabulation indicates the depths in feet of probable increases in initial daily production and their amounts in barrels.

Depth Below Surface	*Depth Below Top Lime*	*Cumulative Production*	*Gain*	*Remarks*
		Less than 10 Barrels		
4,045-4,055	0-10			
4,055-4,065	10-20	190	180	"TOP PAY"
4,084-4,100	39-55			Probable increase
4,100	55	250	70	
4,110-4,116	65-71			Porous cuttings
4,143-4,148	89-103			Porous cuttings
4,150	105	350	100	Approximate figures
4,165-4,181	120-136			Definite increase
4,181	136	450-500	100-150	
4,203	158	*800+	300+	"CAPPS PAY"
4,220	175			First WATER
4,220-4,245	175-200			Much WATER

*First 24 hours, 889 barrels. Later, during a two weeks' testing, the average of the well was 700 barrels per day.

Gravity determinations of the oil from the "White lime" vary from 33° to 37° A. P. I., and the United States Geological Survey describes its base as Intermediate B, meaning that it "verges on asphaltic."

Subjoined is a list of fluid pressures in the "White lime" reservoir determined with a bottom-hole pressure bomb. These wells of the Amerada Petroleum Corporation are the only wells that have been tested in the Hobbs field, but extensive tests are planned. The tests were made during January, 1931. In each test the depth of the bomb is given in feet and its elevation in feet *below* sea-level. The pressure is stated in pounds per square inch, and the approximate total number of barrels of crude oil that each well produced prior to the time of the test is estimated.

Well	*Location*				*Depth*	*Elevation*	*Pressure*	*Production*
		Sec.	*T.*	*R.*				
State 4B	NW. ¼	29	18	38	4,144	−495	1,500	51,000
State 4B	NW. ¼	29	18	38	4,200	−551	1,527	
State 1A	NE. ¼	32	18	38	4,135	−496	1,500	145,000
State 1B	NW. ¼	29	18	38	4,150	−501	1,537	48,000
State 3B	NE. ¼	29	18	38	4,180	−534	1,523	42,000
McKinley 2	NW. ¼	30	18	38	4,200	−545	1,523	232,000
State 1C	NE. ¼	36	18	37	4,200	−545	1,500	900

In the dry holes around the field information about fluid pressure in the "White lime" is almost lacking. Only one well, the Midwest's Wright No. 6, SW. ¼, Sec. 14, T. 19 S., R. 38 E., supplies even questionable data. At 4,275 feet (672 feet below sea-level) this well reached water which rose 3,000 feet[1] in several days. When the total depth was 4,500 feet, 3,500 feet of water was reported in the hole, that is, it had risen to within 1,000 feet of the surface. Under these conditions the pressure on the water reservoir at 4,275 feet is calculated as 1,420 pounds per square inch. No doubt if accurate determinations were made, the

[1]Reported by driller. Unfortunately, these matters have always been left to the driller and are very carelessly determined. A reported "hole full of water" in West Texas or New Mexico often means merely that water rose in the hole and that the driller was unable to bail it down. When 3,000 feet of water are reported in a 4,000-foot hole, it means that the driller, estimating the number of revolutions of the sand reel as the bailer was run in or out, reckoned roughly that the surface of the water was 1,000 feet below the derrick floor. There is need for accurate information here. Successive accurate determinations of water level by stringing out will determine both the pressure in the reservoir and the rate of flow of water into the drill hole. Perhaps less is known about subterranean fluid pressures in the Permian basin (excepting within the oil fields) than about any other ascertainable geologic facts.

pressure off structure in the "White lime" reservoir would be found to be equivalent to the pressure within the oil and gas pool.

Most members of the "White lime" contain no sand, but persistent sandstone beds occur near the middle of that formation. In the discovery well, which was drilled through 200 feet of "White lime," these are 85-100 feet below the top, and the sand grains comprise perhaps 25-50 per cent of the cuttings from the 15-foot interval. Secondary calcite is also a noteworthy constituent. The same beds have been found in similar position in the "White lime" cores and samples from many other wells. They seem to record a locally important interruption of "White lime" sedimentation.

Very black carbonaceous shale is also a minor constituent of the "White lime." Gastropod-like fossils have been found, but no identifications reported. Oölitic cores are obtained from below the top oil and gas—not yet in the bluish cap rock above it—but ordinarily from the lower part of the "White lime" near the "Capps pay."[1] As in the productive limestone of the Hendrick pool, Winkler County, Texas, pressure sutures[2] also occur in the "White lime" at Hobbs. In the "White lime" cores from The Texas Company's State No. 1C, NE. ¼, Sec. 25, T. 18 S., R. 37 E., oölites occur and pressure sutures are plentiful.

Dark anhydritic limestone.—The discovery well drilled 200 feet of "White lime" and must have nearly penetrated it, but the only well at Hobbs to penetrate underlying beds was the Midwest's Wright No. 6, SW. ¼, Sec. 14, T. 19 S., R. 38 E., a dry hole at the southern end of the field. Wright No. 6 drilled 190 feet of "White lime" and 110 feet of a subjacent, dark, anhydritic, magnesian limestone, which is correlated by Neil H. Wills[3] with the San Andres limestone on the north, where that formation becomes more clearly defined. The correlation is based on the microscopic examination of cuttings from many wells and attendant subsurface studies. The lithology, at least, of the dark limestone at Hobbs is identical with that of the upper San Andres.

Ten miles southeast of Hobbs in Gaines County, Texas, the Louisiana Oil Refining Corporation's Ralph No. 1, SW. ¼, Sec. 7, Blk. A-28, Public School Land, was drilled through 155 feet of "White lime" and 250 feet into the subjacent dark anhydritic limestone. Eight miles east of Ralph No. 1, also in Gaines County, the Humble Oil and Refining

[1]See foregoing tabulation showing "White lime pays" in discovery well.

[2]A. W. Grabau, *Principles of Stratigraphy* (1913), pp. 786-89; also W. H. Twenhofel, *Treatise on Sedimentation* (1926), pp. 518-21, paragraph on stylolites.

[3]Geologist, The Midwest Refining Company, Roswell, New Mexico.

Company's Carswell No. 1, NW. ¼, Sec. 23, Blk. A-27, Public School Land, was drilled through 160 feet of "White lime" and 280 feet into the subjacent dark anhydritic limestone.

BOTTOM-WATER LEVEL

A little bottom water was found in the discovery well at 4,220 feet, or 614 feet below sea-level. When the well was deepened to 4,245 feet, much more was found. It was successfully plugged back.

The Ohio Oil Company's State No. 1, SW. ¼, Sec. 9, T. 19 S., R. 38 E., at 611 feet below sea-level, yielded about 60 barrels of oil daily and considerable bottom or edge water. After being deepened to 710 feet below sea-level, it yielded much more water and was plugged back. The structural position of the "White lime" in this well is such that it must be at the extreme edge of the oil pool.

From these two occurrences it was unanimously assumed by the operators, in view of experience with limestone reservoirs in other fields, that a water table exists at Hobbs approximately 610-615 feet below sea-level. Consequently all subsequent wells were bottomed at less depth. The average bottom-hole elevation of Hobbs oil wells is 556 feet below sea-level. The minimum[1] is 507 feet;[2] the maximum,[3] 611 feet.[4]

The assumed relations are illustrated in the cross section (Fig. 7). Within the approximately 200 feet of porous "White lime" at Hobbs, no doubt such bottom-water conditions prevailed until recently disturbed by production, but one can only conjecture whether or not they are affected by the subjacent dark anhydritic limestone, which, on the crest of structure, probably rises 50-100 feet above the assumed water table.

Although the Texas' Selman No. 1, SE. ¼, Sec. 15, T. 19 S., R. 38 E., a small edge well at the extreme southern end of the pool, was drilled to only 585 feet below sea-level, it disclosed a little bottom or edge water that either was exhausted or was successfully plugged off.

Besides the previously described Ohio well in Sec. 9, only two other wells in the field were showing water on March 31, 1931, namely: the Amerada's State No. 1C, NE. ¼, Sec. 36, T. 18 S., R. 37 E., producing

[1]Excluding one well, the Midwest's Byers No. 33, which was bottomed 408 feet below sea-level in the top "White lime pay." It gauged 21,249 barrels daily, nevertheless.

[2]The Amerada's State No. 2A, NE. ¼, Sec. 32, T. 18 S., R. 38 E.

[3]Excluding the aforedescribed Ohio and discovery wells.

[4]The Midwest's Capps No. 31, SW. ¼, Sec. 3, T. 19 S., R. 38 E.

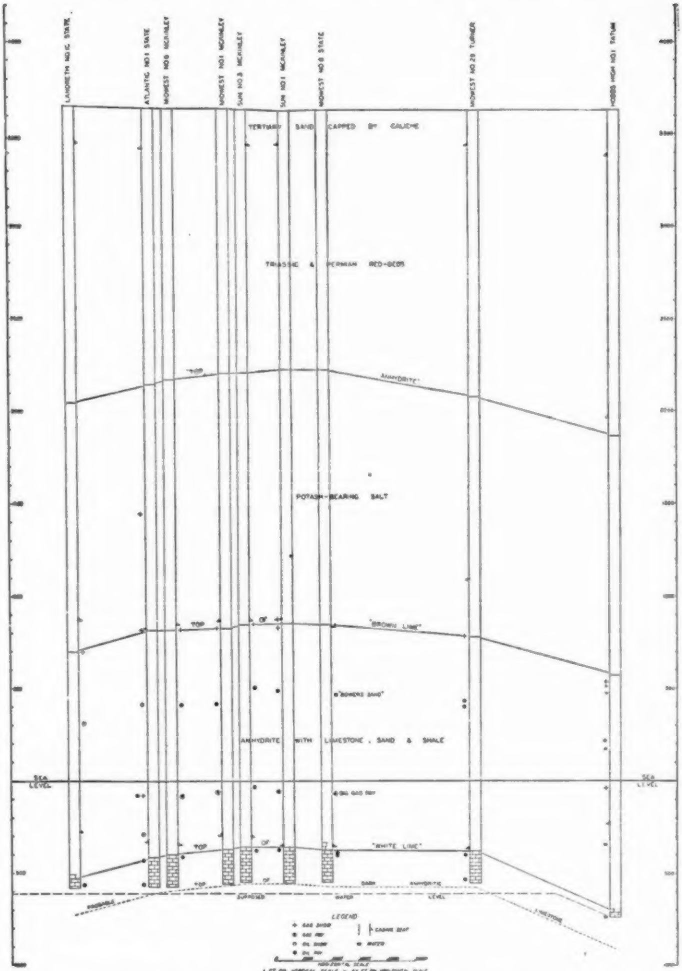

FIG. 7.—East-west cross section of Hobbs field along township line between T. 18 S. and T. 19 S., R. 38 E.

8 per cent water, total depth 581 feet below sea-level; and the Landreth's State No. 1C, NW. 1/4, Sec. 6, T. 19 S., R. 38 E., producing an average of 6 per cent water in small recurrent flows, total depth 579 feet below sea-level. Both are structurally low, and may be termed edge wells.

RELATION OF POROSITY TO STRUCTURE

That the porosity of the "White lime" at Hobbs is related to its structure is obvious. In general, the limestone is most porous on the crest of the anticline, less porous on the flanks, least porous beyond the limits of the oil pool.

Determinations of the actual porosities of limestone reservoirs are not practicable because the really productive openings are so large (ranging in size from "mouse holes" to caverns) that core recovery is almost impossible. As previously stated, core loss is a better indication of a limestone "pay" than the recovery of porous material that bleeds oil. The only index of porosity in the Hobbs field is initial production of oil. Figure 8 shows initial productions by four patterns on a contour map of "White lime" structure in an attempt to illustrate graphically, though inexactly, the relation between the porosity and the structure of the "White lime."

Some of the possible reasons why initial production does not everywhere correspond with porosity follow. 1. The greater amount of gas in the top of the structure may there cause a more rapid outflow of oil from the same space than the less amount of gas on the flanks. 2. On the contrary, certain high wells may have a great excess of gas and correspondingly less oil. This was true of some of the wells high on structure which gauged less than 5,000 barrels a day. The production of oil has recently caused local "gas caps" to form and spread, thus introducing more wells into this category. 3. A well may fortuitously drill into a channel, crevice, or other opening so connected as to drain oil rapidly from considerable distance, thus gaining a greater initial production than the average surrounding porosity indicates.

As against the first argument, two wells in Sec. 15, T. 19 S., R. 38 E., near the center of the north line, show that great local porosity on the flanks of the structure may cause large initial production regardless of less gas.

Four dry holes at Hobbs penetrated the "White lime" where it was structurally too low to produce. Two of these disclosed considerable water, but not great amounts of it, in the top porous beds of the "White

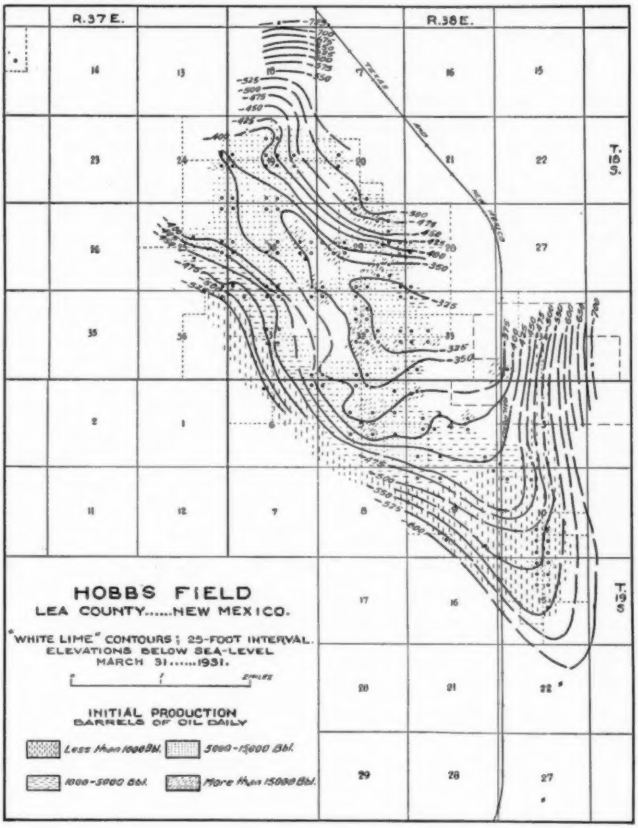

FIG. 8.—Relation of initial production to present "White lime" structure.

lime," and were drilled no deeper. In the other two were found only showings of oil, gas, and water in these top beds and deeper drilling resulted in the finding of considerable water—in one, in the middle sandy members; in the other, not far below the sand.

The top productive member of the "White lime" is cavernous on the crest of the structure, fairly porous on the flanks, and off structure is in places only very slightly porous, in other places somewhat porous. On the flanks, the lower porous members, particularly the "Capps pay'

(all relatively unimportant on the crest), generally yield much more oil than the top member.

In an attempt to relate porosity to folding that occurred shortly after "White lime" deposition, or to topography due to such folding plus erosion, the same patterns denoting initial productions are superimposed (Fig. 9) on contours which indicate the attitude of the top of the "White lime" during that Permian epoch in which the "Brown lime" was being deposited as a horizontal sedimentary formation. The crest of the fold is nearly the same. Perhaps the occurrence of two "hills," one in Sec. 33 and 34, T. 18 S., the other in Sec. 5, T. 19 S., R. 38 E., has some connection with the large oil wells there found.

It may be worth while to emphasize again that prolific production at Hobbs is not confined to any steep basinward dip.[1]

STRUCTURAL HISTORY

Age of folding.—The folding at Hobbs seems to have been progressive during the Permian period. Nevertheless, most of the existing structure is the result of uplifts that occurred in two distinct epochs. To be specific: nearly one-third of the folding happened after the deposition of the "White lime" and before the deposition of the "Brown lime;" and nearly two-thirds subsequent to the deposition of the Rustler formation. The latter folding, or at least a considerable part of it, was probably post-Triassic and certainly pre-Pliocene.

Pre-"Brown lime" folding.—Figure 9 approximately represents the attitude of the surface of the "White lime" at the time when the "Brown lime" was being deposited horizontally. Some of the local irregularities are due to inaccurate choice of the "Brown lime" key horizon or of the top of the "White lime," more often the former.[2] Some may be due to uplift and slight erosion of the "White lime" immediately after deposition. Manifestly the Hobbs structure already existed in "Brown lime" time.

It is not known exactly how much of the folding represented in Figure 9 happened immediately after the deposition of the "White lime." One can not turn for enlightenment to intermediate key horizons because

[1]This fact, coupled with other items of regional structure in New Mexico, renders very improbable the proposed northwestward extension through Hobbs to Artesia of the steep east flank of the Central basin platform of West Texas. In the Artesia district a plateau is quite untenable; there is no north side for it. See Lon D. Cartwright, Jr., "Transverse Section of Permian Basin, West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), p. 974.

[2]The accuracy of the "White lime" datum also is somewhat affected by crooked holes. In the preparation of the contour maps, crooked hole corrections were available for a very few wells only.

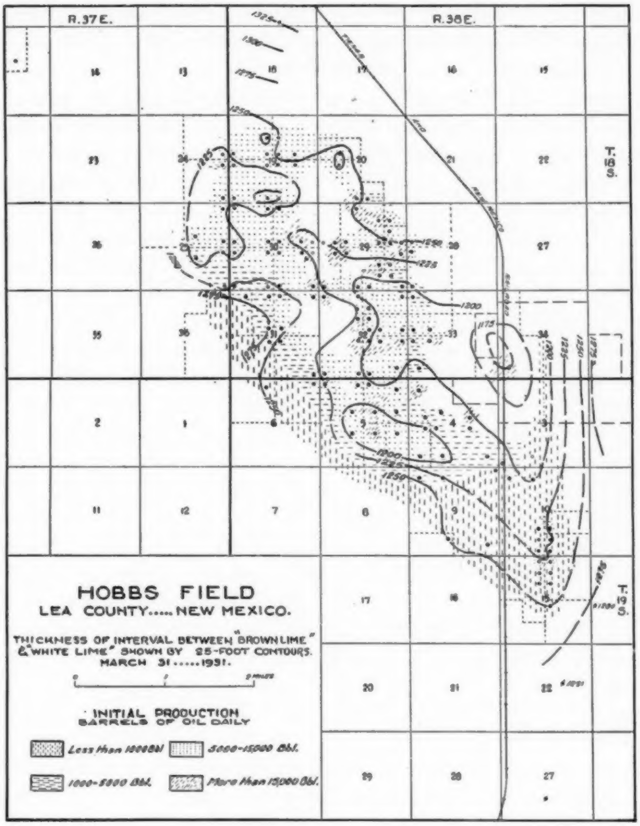

FIG. 9.

insufficient cores and samples make the choosing of them, in many wells, not a simple matter of identification, but a matter of estimating their position by correlation with other wells, thus eliminating the very data sought.

If most of this folding occurred at the close of the "White lime" epoch, evidence of that fact should be found in the sequent "sandy section." In the first place, the variant interval contoured in Figure 9 should be accounted for largely by thinnings and thickenings of "the

sandy section." In this respect the evidence is negative or contradictory. On the west and on the northwest part of the structure the normal 100 feet of "the sandy section" seems, in certain wells that were cored, to be thickened to 150 feet, but this is based on the illusory previously discussed disappearance of anhydrite and becomes unconvincing when the National Securities samples[1] from a locality 4 miles west are considered. Conversely, "the sandy section" is not thickened, but is only 90 feet thick in the low Midwest's Wright No. 6, SW. ¼, Sec. 14, T. 19 S., R. 38 E., as compared with 100 feet in the discovery well; and this may be due to an access of older anhydrite from the east.[2] The second kind of evidence is more favorable. In cores of "the sandy section" from certain wells, conglomeratic material containing small fragments of the bluish limestone has been found as high as 40 feet above the top of the "White lime." Presumably considerable uplift occurred before "the sandy section" time and some erosion occurred during that epoch.

Development of porosity.—One not yet committed to any theory may reserve his judgment concerning the origin of the porosity in the lower part of the "White lime," but the condition of the top porous member seems too significantly related to structure to be thus passed by. It is cavernous on the top, porous on the flanks, and off structure almost dense, and these remarks apply as well to the pre-"Brown lime" structure of the "White lime" as to the present structure of that formation.

If this condition was caused by uplift into the open air and by weathering therein, is the porosity composed of continuous cavities that formed just above an ancient water table? If so, why does the porous member so nearly parallel the top "White lime" surface,[3] and not horizontally truncate the structure shown in Figure 9? Can the answer be that the post-"White lime" uplift was a broad one that was weathered, resubmerged, buried, and then sharply accentuated by later pre-"Brown lime" folding?

What is the origin of the dense bluish limestone everywhere superjacent to the top porous member?

Are the lower porous members of the "White lime" representative of other levels of the ancient water table? Or were they formed during

[1]See second paragraph of the description of "the sandy section" under STRATIGRAPHY.

[2]The evidence should be clear-cut in the low Hobbs High Oil Company's Tatum No. 1, SW. ¼, Sec. 35, T. 18 S., R. 38 E., if anywhere, but there the critical samples are missing.

[3]See third paragraph of the description of the "White lime" under STRATIGRAPHY.

earlier and briefer periods of uplift and weathering? Advocates of the hypothesis that porosity in limestones is developed only by subaerial erosion may find in the sand and secondary calcite of the middle sandy members needful evidence of a local uplift of brief duration during middle "White lime" time.

Data are submitted and these questions propounded, but no answers can be given here.

Certain geologists may argue that the "White lime" was not weathered by vadose water, but that it existed as a broad, low, and porous limestone "reef" (a built-up section) until buried by the sequent series of evaporites.

Possibly the oil itself induces additional solution of its own limestone reservoir, thus increasing the porosity.[1] Water analyses verify the fact that the proximity of oil pools causes the sulphates (SO_4) of bottom and edge water to be reduced to hydrogen sulphide (H_2S). An invariable concomitant of the approximate disappearance of sulphates is the appearance of the carbonates (HCO_3 and CO_3) and sulphides (S). These carbonates look suspiciously like the end products of the reaction[2] of petroleum hydrocarbons with the sulphates, but may partly originate through the dissolving of the limestone reservoir by organic or hydrosulphuric acids, this reaction proceeding as the oil gradually accumulates into a pool and displaces the water from the top of the structure. Absorption of carbon dioxide (CO_2) by the oil and gas would promote the reaction. The solution should be greatest on a quaquaversal crest, where the freshest sulphate waters are longest in contact with accumulating oil.

Post-"Brown lime" folding.—Figure 10 approximately represents the attitude of the "Brown lime" key horizon when the "Top anhy-

[1]An idea gained from conversations with E. W. Shaw and L. A. V. Fowle.

[2]Hypothetical type reaction

$$8\, C_mH_n + (n+4m)\, R_2SO_4 = 8m\, CO_2 + (n+4m)\, R_2S + 4n\, H_2O$$

The presence of sulphate-reducing bacteria is said to be prerequisite to this sort of reaction: see, R. L. Ginter, "Causative Agents of Sulphate Reduction in Oil-Well Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 2 (February, 1930), p. 151, Fig. 1.

Formation of carbonates

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

Generation of H_2S

$$R_2S + H_2CO_3 \rightleftarrows R_2CO_3 + H_2S$$

N. B., the absorption of CO_2 and H_2S by the oil and gas promotes these three reactions. Both compounds are plentiful in "White lime" gas, but absent or practically absent from stratigraphically higher gases (see GAS ANALYSES *ff.*).

drite" was being deposited horizontally. Irregularities not due to actual folding may be introduced by either or both of the markers as already discussed. Whereas the Hobbs structure is discernible in this contouring, the axis, compared with those on the other maps, is offset on the northeast, although it more nearly coincides with the axis of pre-"Brown lime" folding (Fig. 9) than with the axis of the subsequent folding of the "Top anhydrite" (Fig. 4). Its primary effect, therefore, is to diminish somewhat the dip on the northeast flank of the structure. However, the map indicates that the local uplift at Hobbs was still active during the deposition of the potash-bearing salt.

Latest folding.—Figure 4 depicts the folding since the Rustler epoch. It is impossible to determine whether the Santa Rosa sandstone is equally folded at Hobbs. Samples are lacking, and, even if they were plentiful, this thick variable sandstone formation would still be an inadequate marker for local correlations. Regionally, however, in structurally low wells several miles distant from Hobbs in several directions, the Santa Rosa sandstone seems to be almost as much displaced as the "Top anhydrite." The increase of interval in these wells between the Tertiary blanket and the "Top anhydrite" seems to be taken up by additional, younger Triassic red beds. Probably a large part of the folding shown in Figure 4 is post-Triassic in age, and it is all older than the late Tertiary deposits of the Llano Estacado.

Relative magnitudes of folding.—Each of the four columns in the following tabulation gives the total structural descent in feet of the "White lime" from a structurally high well to a low well on the flank of the Hobbs structure. The four pairs of wells chosen define the folding on four different sides of the anticline. This folding is chronologically analyzed into three components. A minus sign denotes an epoch of folding that diminished the dip instead of increasing it.

Epoch of Folding	*I*	*II*	*III*	*IV*
Pre-"Brown lime"	110	130	94	40
During "Salt time"	27	−30	−32	15
Latest	224	223	203	136
Total	361	323	265	191

I. Shell's McKinley 7, 19-18-38, to Landreth's State 1A, 7-18-38.
II. Midwest's Turner 29, 34-18-38, to Hobbs High's Tatum 1, 35-18-38.
III. Ohio-Phillips' State 2, 32-18-38, to Midwest's Wright 6, 14-19-38.
IV. Ohio-Phillips' State 4, 32-18-38, to Landreth's State 1C, 6-19-38.

In this tabulation the four numbers that are designed to indicate the folding during "Salt time" are less than the probable errors of de-

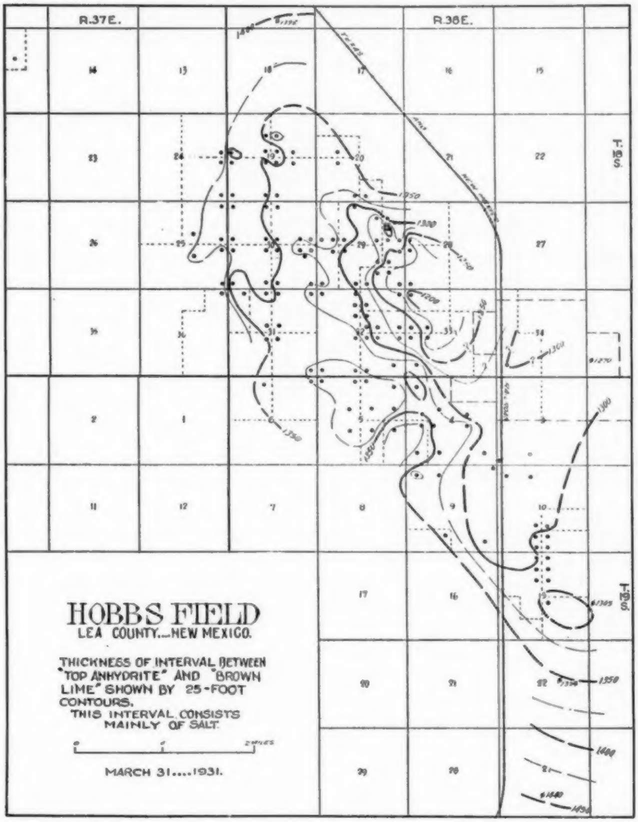

FIG. 10.

termination of the "Top anhydrite" and "Brown lime" horizons from which they are calculated. The significant folding between these particular wells occurred in the other two epochs.

The choice of other wells gives somewhat different results, as may be seen in the following figures, in which the folding during "Salt time" is nearly as important as that which occurred during either of the other two periods.

Epoch of Folding	*V*	*VI*
Pre-"Brown lime"	95	55
During "Salt time"	90	55
Latest	106	69
Total	281	179

V. Continental's State 3B, 33-18-38, to Midwest's Wright 6, 14-19-38.
VI. Ohio-Phillips' State 4, 32-18-38, to Amerada's State 1C, 36-18-37.

To sum up, one may say that pre-"Brown lime" folding accounts for almost one-third of the Hobbs structure; that the latest folding (probably post-Triassic) accounts for almost two-thirds of the structure; and that these results are considerably but erratically modified by folding contemporaneous with the deposition of the potash-bearing salt.

ORIGIN AND ACCUMULATION OF OIL

No contribution to this abstruse subject is offered here, but only a few questions which are suggested by the subsurface conditions at Hobbs.

A tenet of the complete faith in subaerial origin of limestone reservoirs is that the migration of fluids through unweathered limestone is an impossibility. Matter can not move in a plenum. If one decides that point thus *a priori*, he accepts as a matter of course the theory that oil originates at unconformities and is indigenous to its reservoir.

The "Bowers sand" and "Big gas pay" at Hobbs suggest certain questions. Here are large accumulations of oil and gas that occur in sand members interbedded with saline residues. Did the oil and gas originate within these reservoir beds? Evaporite series have heretofore been considered unfavorable places to expect commercial quantities of oil excepting where they overlie deeper pools in beds of less saline origin.

If ordinary limestone is dense, anhydrite is denser. Did the oil and gas migrate upward into the "Bowers sand" and "Big gas pay" through several hundred feet of limestone and anhydrite by following the joints caused by folding? If so, why not also upward into the "White lime" from beds still deeper?

The fluid pressures in the "Bowers sand" and in the "Big gas pay" are approximately the same as in the "White lime." The fact that these pressures are all so nearly equal may suggest to some geologists a past or present connection between the reservoirs.

The gravity of the oil in the "Bowers sand" is 37°-40° A. P. I. as against 33°-37°, which is the gravity of the oil in the "White lime." Corresponding with its lighter gravity, "Bowers sand" oil has a paraffine base, whereas the base of "White lime" oil "verges on asphaltic."

The chief difference between the gases at Hobbs is the presence of notable percentages of CO_2 and H_2S in "White lime" gas, which is produced with the oil, and the practical absence of both of these compounds in the overlying gases. The "Big gas" and "Bowers sand" gas contain large percentages of nitrogen. Nitrogen is a characteristic constituent of gases from evaporites everywhere. A gradation seems to exist among gases in the Permian basin in southeastern New Mexico. At one end is the "Big lime" gas with little nitrogen and high heating value (exceeding 1,000 B. t. u. per cubic foot). Next are gases produced from clastic reservoir beds in the overlying anhydrite having much nitrogen and a low heating value (approximately 700 B. t. u.). Some have too much nitrogen to be sold commercially, though the gas will burn. At the non-inflammable end of the gradation is the gas that occurs in the salt.

OIL ANALYSES

"*Bowers sand*" *oil.*—The following analyses are published through the courtesy of the United States Geological Survey. On July 12, 1930, duplicate samples of "Bowers sand" oil were taken from the separator at the Humble's Bowers No. 4A, SE. 1/4, Sec. 30, T. 18 S., R. 38 E. Both samples were analyzed in the Survey's field laboratory at Midwest, Wyoming.

Samples taken by T. G. Taylor
Depth to top of sand 3,161 feet. Depth of hole 3,260 feet
9 5/8-inch casing cemented at 2,750 feet with 650 sacks
Initial production 234 barrels oil, 1,500,000 cubic feet gas daily
Analyses by J. G. Crawford, July 31, 1930

	Sample I	*Sample II*
Gravity of crude	39.4° A.P.I.	38.3° A.P.I.
Centrifuge: B. S., mud and water	0.80 per cent	0.15 per cent
Sulphur content	1.07 per cent	0.34 per cent
Universal Saybolt viscosity at 100° F.	43	46 sec.
DISTILLATION (AIR)		
First drop	106°	99° F.
Less than 392° F.	37.3 per cent—58.4° A.P.I.	34.3 per cent—57.2° A.P.I.
392° F. to 482° F.	9.3 per cent—44.0° A.P.I.	10.7 per cent—43.7° A.P.I.
482° F. to 527° F.	6.0 per cent—40.4° A.P.I.	5.5 per cent—40.2° A.P.I.
VACUUM DISTILLATION AT 40 MM.	*Per Cent*	*Per Cent*
Less than 392° F.	4.7	4.8
392° F. to 482° F.	9.3	10.2
482° F. to 527° F.	5.7	4.8
527° F. to 572° F.	4.7	4.9
Residuum	23.0	14.8
BASE	Paraffine	Paraffine

"*White lime*" *oil.*—The subjoined analysis is published through the courtesy of the United States Geological Survey. On September

25, 1929, a sample was taken from the "lead line as oil was flowing into tank" at the discovery well. It was analyzed in the Survey's field laboratory at Midwest, Wyoming.

Sample taken by Foster Morrell
Top "White lime" 4,045 feet. Total depth 4,245 feet, plugged back to 4,217 feet
8¼-inch casing set at 4,040 feet
Initial production 700 barrels daily
Analysis by J. G. Crawford, October 15, 1929

Gravity of crude	34.8° A. P. I.
Centrifuge: B. S., mud, and water	0.1 per cent
Sulphur content	1.47 per cent
Universal Saybolt viscosity at 100° F.	43 sec.
DISTILLATION (AIR)	
First drop	115° F.
Less than 392° F.	34.7 per cent—56.6° A.P.I.
392° F. to 482° F.	9.0 per cent—38.5° A.P.I.
482° F. to 527° F.	6.0 per cent—34.3° A.P.I.
VACUUM DISTILLATION AT 40 MM.	*Per Cent*
Less than 392° F.	4.7
392° F. to 482° F.	8.3
482° F. to 527° F.	5.0
527° F. to 572° F.	4.7
Residuum	27.6
BASE	Intermediate B*

*Note: Intermediate B is a base verging on asphaltic.

WATER ANALYSES

The various subterranean waters at Hobbs are readily distinguished by chemical analysis.

Tertiary water.—On October 16, 1927, a sample of water from 50-62 feet in the discovery well was dipped from the top of the bailer. Depth of hole was 62 feet. The following analysis was made by H. K. Frank, in the laboratory of The Midwest Refining Company's gas plant, Salt Creek field, Wyoming.

	P. P. M.	*Reacting Values Per Cent*
Na	29	9.1
Ca	72	27.3
Mg	22	13.6
SO_4	82	13.0
Cl	42	9.0
CO_3	0	0.0
HCO_3	226	28.0
Total P. P. M.	473	100.0
Total solids by evaporation	420	
Specific gravity	1.002	

Sodium calculated, not actually determined

Upper Dockum water.—On March 28, 1929, a sample of water from a Triassic sand at 455-62 feet was taken from the bailer of the Midwest's Capps No. 31, SW. ¼, Sec. 3, T. 19 S., R. 38 E., depth of hole 465 feet. Analyzed, April 13, 1929, by H. K. Frank.

	P. P. M.	*Reacting Values Per Cent*
Na	2,363	43.3
Ca	200	4.2
Mg	70	2.5
SO_4	1,010	8.8
Cl	3,370	40.3
CO_3	0	0.0
HCO_3	134	0.9
Total P. P. M.	7,147	100.0
Total solids by evaporation	6,740	
Specific gravity	1.004	
Organic matter present		
Sodium calculated, not actually determined		

Santa Rosa water.—On December 21, 1927, a sample of water from the Santa Rosa sandstone was taken from the bailer of the discovery well, depth of water 1,235-1,250 feet, depth of hole 1,250 feet. Analyzed, January 5, 1928, by H. K. Frank.

	P. P. M.	*Reacting Values Per Cent*
Na	730	49.5
Ca	6	0.5
Mg	Trace	0.0
SO_4	716	23.4
Cl	143	6.3
CO_3	51	2.7
HCO_3	685	17.6
Total P. P. M.	2,331	100.0
Total solids by evaporation	1,660	
Specific gravity 1.005		
Sodium calculated, not actually determined		

Water from "Big gas pay."—The chemical composition of the water from the "Bowers sand" is probably nearly identical with that from the "Big gas pay." Both are very salty.

On July 15, 1930, a sample of water from the "Big gas pay" was taken from the bailer of the Midwest's Byers No. 33, NE. ¼, Sec. 4, T. 19 S., R. 38 E., depth of water 3,720-3,725 feet, depth of hole 3,725 feet. Analyzed, August 7, 1930, by H. K. Frank.

	P. P. M.	*Reacting Values Per Cent*
Na	84,292	34.9
Ca	14,200	6.8
Mg	10,500	8.3
SO_4	682	0.14
Cl	185,000	49.81
CO_3	0	0.00
HCO_3	279	0.05
Total P. P. M.	294,953	100.00
Total solids by evaporation	284,700	

Sodium calculated, not actually determined

Analysis not corrected for specific gravity; hence, actual salinity is approximately 50,000 P. P. M. less than reported above

"White lime" waters.—Subjoined is an analysis of the first bottom water encountered in the discovery well. Sample taken from bailer, November 8, 1928, water coming from 4,220 feet, total depth. Analyzed, November 16, 1928, by H. K. Frank.

	P. P. M.	*Reacting Values Per Cent*
Na	2,733	38.4
Ca	280	4.6
Mg	262	7.0
SO_4	41	0.3
Cl	4,107	37.8
CO_3	0	0.0
HCO_3	2,240	11.9
Total P. P. M.	9,663	100.0
Total solids by evaporation	7,960	

Sodium calculated, not actually determined

Specific gravity 1.010

H_2S present

No iodine

The following is an analysis of bottom water from the Ohio's State No. 1, SW. ¼, Sec. 9, T. 19 S., R. 38 E., an extreme edge well, which first found water at 4,208 feet, was deepened to 4,312, finding more water, and plugged back to 4,208 feet (4,213 feet Steel Line Measurement). The sample analyzed was taken after oil and water had been produced for nearly a year at the rate of approximately 20 barrels daily. Analyzed, December 5, 1930, by R. E. Thurn, United States Bureau of Mines. Notice the larger amount of sulphate than in the preceding analysis.

	P. P. M.	Reacting Values Per Cent
Na	3,026	40.66
Ca	222	3.42
Mg	233	5.92
SO_4	315	2.02
Cl	4,681	40.78
CO_3	0	0.00
HCO_3	1,421	7.20
OH	0	0.00
Total solids	9,898	100.00

Specific gravity at 15.6° C. (60° F.) 1.0082

GAS ANALYSES

"*Big gas.*"—Subjoined is an average analysis of a sample containing the combined gases from the "Big gas pay," the "Bowers sand," and the "Brown lime."

	Per Cent
H_2S	nil
CO_2	0.07
O_2	0.07
CH_4	58.
C_2H_6	21.
N_2	20.

"*White lime*" *gas.*—Subjoined are two analyses of gases produced with the oil. The samples were collected in aluminum containers, and were analyzed by H. W. Young, at The Midwest Refining Company's gas plant, Salt Creek field, Wyoming.

	I Per Cent	II Per Cent
H_2S	2.27	1.05
CO_2	4.00	5.25
O_2	1.06	0.81
CH_4	52.19	63.30
C_2H_6	7.16	3.34
Propane	13.31	9.09
Isobutane	2.49	1.32
Normal butane	6.99	5.29
Pentanes and heavier	4.55	4.18
N_2	5.98	6.37
	100.00	100.00
Observed gravity	1.050	0.933
Calculated gravity	1.044	0.938

I. Sample taken from meter station No. 13 (Phillips gas plant); gas from discovery well and the Midwest's State No. 8, NW. ¼, Sec. 10, T. 19 S., R. 38 E.
II. Sample from the Midwest's Byers No. 33, NE. ¼, Sec. 4, T. 19 S., R. 38 E.

DRILLING METHODS

Fortunately, the Humble's Bowers No. 1 was drilled with rotary tools. Its discovery of the "Big gas" and of flush production of gas and oil under high pressure in the "White lime" determined subsequent drilling methods in the Hobbs field. In many wells the hole is spudded through the Tertiary beds by means of a portable spudding machine that is moved on and off the derrick floor. Then rotary equipment is rigged up and the Red-beds are drilled. In the southern end of the field, where the "Big gas" is absent, the change to cable tools is generally made when the hole has reached the "Top anhydrite," but in some wells it is made near the top of the "Brown lime." On the crest of the structure rotary tools are used exclusively to drill all the way, and the oil and gas in the "Bowers sand" and "Big gas" are kept under control with weighted mud fluid; in the "White lime," with water.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 1 (JANUARY, 1932), PP. 91-100, 2 FIGS.

GEOLOGICAL NOTES

OCCURRENCE OF FLUORITE IN MONROE FORMATION OF VERNON TOWNSHIP POOL NEAR MOUNT PLEASANT, MICHIGAN

In a paper read before the Michigan Academy of Science, Arts, and Letters on March 20, 1931, the origin and occurrence of fluorite in two wells in the Vernon pool were described by the writers. Mellon-Pollock's Crowley No. 1, Sec. 26, T. 16 N., R. 4 W., at a depth of 3,743-3,753 feet, encountered large deposits of the mineral and in Mellon-Pollock's Durnin No. 1, Sec. 22, T. 16 N., R. 4 W., at 3,766-3,768 feet, a few fragments were identifiable. This fluorite lines, and in places fills, drusy cavities of the pay horizon of the Dundee or Monroe (Devonian) and occurs along an erosional unconformity between these formations. As the reservoir rock here is a porous limestone and the secondary deposition reduces the pore space, the erratic nature of the wells in the Vernon area may be attributed to its presence in the cavities. Contained hydrocarbons and inclusions of small particles of dolomite within the crystals themselves have colored much of the fluorite brown or black. It is thought that the deposit is secondary as a result of the reworking of old land masses, and that it has no relation to igneous activity of any type. The reasons for this assumption are (1) the lack of igneous intrusions and (2) the improbability of magmatic waters migrating upward through 4,000 feet of sedimentary beds which underlie the Monroe formation and in which are included several hundred feet of salt. In the Vernon Township area the drill penetrates the following formations (as in the Crowley No. 1, T. 16 N., R. 4 W.).

Formation		*Depth in Feet*
Pleistocene		0-305
Pennsylvanian	Saginaw series (coal, shale and sandstone)	305-525
	Parma formation (mostly sandstone)	525-710
Mississippian	Michigan series (gypsum, dolomite, limestone, shale, and gas sand near base)	710-1,353
	Upper Marshall sandstone	1,353-1,516
	Lower Marshall red sandstone and shale	1,516-1,595
	Coldwater shale	1,595-2,418
	Berea (Sunbury) shale	2,418-2,448
	Berea (sandstone and shale)	2,448-2,484

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Formation		*Depth in Feet*
Pleistocene		0-305
Pennsylvanian	Saginaw series (coal, shale and sandstone)	305-525
	Parma formation (mostly sandstone)	525-710
Mississippian	Michigan series (gypsum, dolomite, limestone, shale, and gas sand near base)	710-1,353
	Upper Marshall sandstone	1,353-1,516
	Lower Marshall red sandstone and shale	1,516-1,595
	Coldwater shale	1,595-2,418
	Berea (Sunbury) shale	2,418-2,448
	Berea (sandstone and shale)	2,448-2,484

	Formation	*Depth in Feet*
Devonian	Bedford and Antrim (gray and black shale)	2,484-3,070
	Traverse formation (limestone and shale)	3,070-3,703
	Bell shale (dark gray)	3,703-3,733
	Dundee? absent because of unconformity	-
	Monroe (Fluorite zone 3,743-3,753), oil and gas (120 barrels oil, first 8 hours)	3,733-3,753

P. E. Fitzgerald
W. A. Thomas

Saginaw, Michigan
September 15, 1931

SIMPLE GRAPHICAL METHOD FOR DETERMINING TRUE DIP FROM TWO COMPONENTS AND FOR CONSTRUCTING CONTOURED STRUCTURAL MAPS FROM DIP OBSERVATIONS

Several methods for determining true dip when two components are known have recently been published in this *Bulletin*.[1] A graphical method which is believed to be simpler, more direct, and speedier than any of those described was developed by the writer in the course of recent structural work in the New York-Pennsylvania gas area, where dips are low, exposures few, and contouring on key beds impracticable.

The method is particularly applicable to low dips. One of its greatest elements of simplicity is that in the course of the calculations dips need not be reduced to degrees, though the final result may readily be converted to degrees if desired.

The field observations, which are commonly made by hand level and pacing or tape (because low dips can not be determined satisfactorily by clinometer), may be recorded somewhat as follows: component, down S.30°W., 8 inches in 30 feet; component, down S.15°E., 1½ feet in 120 feet.

From the foregoing information, the first step in determining the true dip is to reduce all observations to common units (generally feet) and to a ratio to unity. Thus, 8 inches in 30 feet is reduced to 1 foot in 45 feet or, expressed as a ratio, 1 : 45. Likewise, 1½ feet in 120 feet

[1] H. W. Kitson, "Graphic Solution of Strike and Dip from Two Angular Components." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 9 (September, 1929), pp. 1211-13.
L. L. Nettleton, *op. cit.*, Vol. 15, No. 1 (January, 1931), pp. 79-82.
M. King Hubbert, *op. cit.*, Vol. 15, No. 3 (March, 1931), pp. 283-86.

becomes 1 : 80. The observations, being reduced, should now be plotted. From a point, *O* (Fig. 1), draw a line bearing S. 30° W. and on it, using any convenient scale (the larger the scale the greater the accuracy), mark off *OA*, whose length is a number of scale divisions corresponding with the second member of the ratio 1 : 45. On a line bearing S. 15° E., scale off 80 divisions to locate point *B*. A line connecting *A* and *B* is

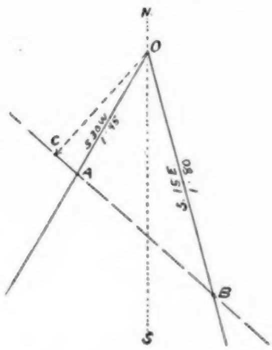

FIG. 1

the strike. A perpendicular *OC* dropped from *O* to *AB* gives the direction of dip, which can be measured with a protractor (in this illustration, S. 41° W.), and the line *OC*, measured in the same scale units as were used in plotting *OA* and *OB*, gives the amount of dip expressed in a ratio such as the ratios for the components *OA* and *OB* (in this illustration, 1 : 44).

This ratio can be converted readily into degrees if desired, but for the purpose of constructing structure maps such conversion is neither necessary nor desirable because the ratio is used directly.

Suppose, for example, that the true dip is as shown, S. 41° W., 1:44. For contouring purposes a conventional dip and strike symbol is drawn, having the strike line of some convenient uniform length, but having the dip line drawn to scale of such length as, on the scale of the map being prepared, would represent the horizontal distance in which the bed drops the amount of one contour interval.

In practice, this is done graphically by preparing a scale converting the ratios directly into map distances. For example, for a dip ratio of 1 : 40 (1 foot in 40 feet) and a contour interval of 25 feet, it is obvious

that the length of the dip arrow on the scale of the map is determined by the proportion 1 : 40 :: 25 : X. X, in this case, is 1,000 feet. In the same way, the length of the dip line for a ratio of 1 : 20 would be 500 feet; 1 : 10 would be 250 feet, and so on. From these figures a scale can be constructed readily from which the length of the dip lines for any ratio can be scaled off directly.

After the preparation of a map in which direction and amount of dip are expressed graphically in this way, Figure 2, a qualitatively correct contour picture of the structure, can be drawn directly because the lengths of the dip lines everywhere represent the proper spacing of the contours and the strike lines represent their directions.[1] How nearly

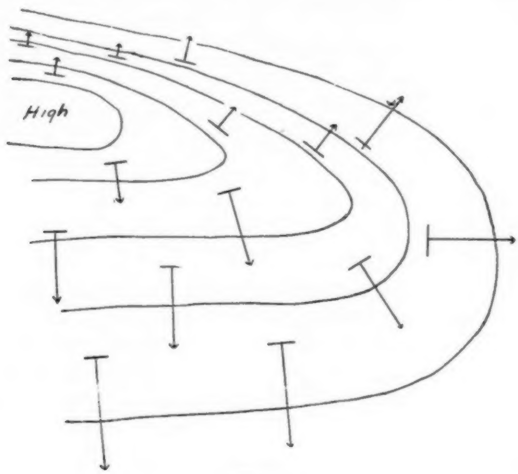

FIG. 2

the result will approach a quantitatively correct delineation of the structure depends on the number of observations and on the skill of the geologist in correctly converting into contours the information graphically set before him.

JOHN L. RICH

UNIVERSITY OF CINCINNATI
CINCINNATI, OHIO
September 28, 1931

[1]The idea of representing dips graphically by drawing dip lines to scale is not original with the writer, but he has been unable to find reference to the original publication.

POSSIBLE SILURIAN AND DEVONIAN STRATA IN VAN HORN REGION, TEXAS[1]

The broader features of the geology of the Van Horn region have been ably set forth by G. B. Richardson in the Van Horn folio,[2] but further details have been obtained during the course of recent work in the region by J. Brookes Knight and the writer. The following note reports the discovery of possible Silurian and Devonian rocks near Van Horn; other observations are reserved for publication later.

In the Van Horn folio the Hueco limestone, at that time assigned to the Pennsvlvanian by G. H. Girty, was shown to lie with marked unconformity on the older rocks, so that all the geologic record between the Montoya limestone (Upper Ordovician) and the Hueco had been completely eroded.[3] Later work has suggested that the actual hiatus is even greater, for R. E. King and the writer[4] have concluded that the greater bulk of the Hueco formation in the Van Horn region is Permian in age.[5] The same writers reported the existence of true Pennsylvanian beneath the unconformity at Marble Canyon (p. 911).

Permian rocks form the capping stratum of all the mountains on the west side of Salt Flat, and in places extend nearly, if not quite, to the bases of the escarpments; the outcrops of the older rocks are discontinuous. The unconformity below the Permian extends across the truncated edges of the older rocks so that its strata overlie the Cambrian or pre-Cambrian on the crests of arches produced by Pennsylvanian folding. In the shallow synclines between the arches, much younger rocks are still preserved; one of these synclinal areas extends northeast under the central part of the Baylor Mountains, and another underlies the region in northern Sierra Diablo between Marble Canyon and Apache Canyon.

[1]Published with permission of the acting director, U. S. Geol. Survey.

[2]*U. S. Geol. Survey Folio 194* (1914).

[3]Richardson does state, however, that "it is possible that some of the limestone, in which fossils have not been found, lying between the Montoya and Hueco limestones, may be of Niagaran age and represent the Fusselman limestone of the El Paso quadrangle" (p. 8).

[4]P. B. King and R. E. King, "Stratigraphy of Outcropping Carboniferous and Permian Rocks in Trans-Pecos Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), p. 922.

[5]The position of the Pennsylvanian-Permian boundary is in dispute. Permian, as it is here used, is a term of convenience, applied to a thick series of rocks in western Texas with late Carboniferous fossils, which lie with great unconformity on strata whose youngest members contain typical Pennsylvanian fossils.

In both these areas fossiliferous Montoya limestone is exposed. On the point of Sierra Diablo 2 miles northwest of the Figure Two Ranch the formation is 250 feet thick, and crops out prominently on the lowest spurs of the mountains. Intervening between it and the Permian basal conglomerates both here and at one spot in the Baylor Mountains are other strata not elsewhere seen in the region. The locality in the Baylor Mountains is on the eastern side, below the high peak with an altitude of 5,560 feet.[1]

Directly above the Montoya are 300 or 400 feet of white, well crystallized dolomite, with few and poorly marked bedding planes. Diagenetic alteration has been so great that fossils are practically unrecognizable, and only a favosite coral and the cross section of a brachiopod, seemingly a pentamerid, were collected. Lithologically, the formation is so nearly the same as the Fusselman dolomite (Silurian) in the Hueco Mountains, on the opposite side of the Diablo Plateau on the west, that the writer has no doubt of their identity.

In places the probable Fusselman is separated from the Permian by 100 feet or more of platy black or brown bituminous shale and shaly limestone, interbedded with lenses and thin beds of white, buff, or dull green chert. Some of the chert is banded by black laminae. The shales contain minute spicules and possible conodonts. The resemblance of the cherts to the bedded chert members of the Caballos formation (Devonian?) at Marathon is very great, and the flaggy shales are reminiscent of parts of the Percha shale (Upper Devonian) in southern New Mexico. In view of these resemblances, there is a possibility that the strata are Devonian in age.

At the south end of the pre-Carboniferous exposures in northern Sierra Diablo, the beds stand nearly vertically, and the next outcrops, a few hundred yards farther south, are of nearly horizontal early Pennsylvanian shales. If there are no structural complications along this contact, the Pennsylvanian rests directly on possible Devonian strata, and the upper Mississippian (such as occurs in the Hueco Mountains on the west) is absent.

The exposures herein described are of interest because of their paleogeographic implications. The Silurian of Sierra Diablo is the easternmost exposure of that system in Texas, though it has been reported[2] in the

[1] At both localities, both the Montoya and the beds between it and the Permian were mapped with the Hueco formation in the Van Horn folio.

[2] S. W. Lowman, "Silurian at Big Lake," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 5 (May, 1930), p. 618. This report is not confirmed, however, in the later publication of Sellards, Bybee, and Hemphill.

subsurface at the Big Lake oil field farther east. The cherts and shales above it may provide a link between the Caballos formation of the Marathon region and the fossiliferous Percha shale of New Mexico. Strata of probable Percha age have been described by Darton[1] in the Franklin Mountains north of El Paso, and the writer and his brother[2] have suggested a Devonian age for cherts and shales in the Hueco Mountains. None of these possible Devonian strata has yielded fossils plentifully, and more thorough search in all of them is desirable. Existence of conodonts in some of the shales has been noticed, and the careful collection and study of material from the doubtful horizons by a student of these fossils would probably go far toward clarifying the stratigraphic relations.

PHILIP B. KING

WASHINGTON, D. C.
October 7, 1931

LATITUDE AND LONGITUDE OBSERVATIONS FOR GEOLOGIC MAPPING[3]

The geologist working in most parts of the United States can plot his field observations directly upon topographic sheets of the United States Geological Survey or upon aerial photographs of the area. He at least has many and accurate control points for locating geologic phenomena, but this assistance is not ordinarily available in foreign countries.

During a recent examination of part of the upper Amazon, as the writer found existing maps to be much in error, he resorted to latitude and longitude observations as a method for correcting rapid traverses which covered wide areas. Many rivers in this area have very even gradients so that a canoe time traverse, frequently corrected by astronomical observations, provides a rapid method for fairly accurate reconnaissance mapping. The method and instruments used in making the observations are here described.

Radio.—A short-wave receiver was used with a range of 15-120 meters or 2,500-20,000 kilocycles. It cost $90.00 complete with ear

[1]N. H. Darton, "Devonian Strata in Western Texas," *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), p. 116.

[2]*Op. cit.*, p. 910.

[3]Made for the Standard Oil Company of California in eastern Peru and Ecuador during 1931.

phones and wave meter. The radio chassis, three standard dry cells, and two 22½ volt B batteries were all built into a well made carrying case with dimensions 11¾ × 11 × 8¾ inches. The weight of the complete unit was 30 pounds. Three R 215-A, Northern Electric "peanut tubes" were used, although improved types of vacuum tubes are doubtless on the market by this time.

Batteries with ordinary usage (30 minutes to 1 hour daily) will last three months. Additional batteries for tropical use should be wrapped in paper and dipped in paraffine. Extra vacuum tubes and grid leak should be carried.

Time signals from Arlington (Washington), as well as Callao, Peru, could be easily picked up in weather of almost any kind. Arlington sends time signals in code at noon, at 10:00 P. M., and at 3:00 A. M., Eastern Standard time. In the United States system, signals begin five minutes before the hour with a tick each second, eliminating, however, the 29th, 51st, 56th, 57th, 58th, and 59th seconds of the first minute. Similar omissions are made during the second minute, except that the 52nd second is silent instead of the 51st. In the third minute, the 53rd second is silent, et cetera. The start of a long dash marks the end of the hour. The signals are easily received after a little practice. Many stations send throughout the day and night. A short-wave set requires a very simple aerial and the ground may be eliminated if necessary. The radio should be carried in a rubber sack and occasionally dried in the sun. Reception at night, of course, is better than during the day.

A little broadcasting was received, especially from the powerful short-wave station of the General Electric at Schenectady, whose programs are heard throughout the world by short-wave enthusiasts. On several occasions, the Indians were allowed to listen through the ear phones, and they showed much interest, but of course could not understand the wonders of the radio, as their experience had never reached farther than the realms of a most primitive jungle life.

Radia Aids to Navigation, or H. O. No. 205 of the United States Navy Department, lists all stations sending time signals, besides giving much other useful information. Cost of book is $0.75.

Chronometer.—An ordinary stop watch costing $45.00 was used. Rate of loss or gain was determined daily so that error in time could be calculated to less than one second for any hour during the twenty-four. This watch was satisfactory, but a second time-piece of slightly better quality, to use in conjunction with the stop watch, would have facili-

tated the work. Watches must be wound at the same time daily, and for tropical use, must be carried in air-tight containers.

American Nautical Almanac, of the United States Printing Office, has a star map and necessary tables for observations on the sun, moon, stars, and planets. The book formerly cost $0.25, but the 1932 edition contains more information and is sold for $0.50.

American Practical Navigator, by Bowditch, or H. O. No. 9 of the United States Hydrographic Office, contains complete tables, explanation, et cetera, for latitude and longitude calculations. The price is $2.25.

Navigation Tables for Mariners and Aviators, by Dreisonstok, or H. O. No. 208 (United States Printing Office) may be used instead of Bowditch. Dreisonstok uses a new, rapid method for latitude and longitude calculations, but if the observer is not thoroughly acquainted with the usual corrections, et cetera, for astronomical work, he should also provide himself with a copy of Bowditch. There are, of course, books other than the two mentioned which contain tables for astronomical calculations.

Rude Star Finder and Identifier, or H. O. No. 2102 (United States Printing Office) provides a partially mechanical method for identifying stars and planets. It is especially useful when only a few stars are visible through small rifts in the clouds, but it is somewhat cumbersome for rough field use, and it may be considered as optional equipment. It costs $5.00.

Sextant.—A sextant with 7-inch limb, costing $135.00, reading to 10 seconds and weighing 9 pounds, was used. Sextants with an electric battery in the handle and with light connections possess several advantages over the ordinary type. The sextant is slightly more accurate than the ordinary transit for determining altitudes, but it can not be used on angles exceeding 60° with the artificial horizon. With the artificial horizon, double the true angle is read, and the range of the sextant's arc is 120°. This prevents latitude shots on the sun at points near the equator, but stars and planets may be used instead.

The index correction of the sextant must be determined frequently, but this requires only a minute or two. In making observation, the instrument vernier is set at zero, the celestial body is observed, and the reflected image brought down to coincide with the image in the artificial horizon, by slowly moving the limb of the sextant. A little practice is required for this operation.

Artificial horizon.—It is unnecessary to buy an expensive horizon for use with the sextant, except for work in very windy spots. An iron

or enameled pie plate with one kilo of mercury is entirely satisfactory. A small frying pan is excellent. Heavy cylinder oil or molasses is just as good as mercury for sun shots, and is less affected by wind, but mercury gives a little better reflection at night. Mercury can not be used in aluminum or tin plates.

In jungle work, small clearings or the broad river banks may be used for observations. In latitude determinations, the celestial body should be observed at culmination, and several different bodies should be observed, both north and south of the observer. This method gives a close check and a point may be determined with a possible error of only a few seconds. Latitude calculations are very simple and require but five or ten minutes each.

Longitude observations must be carefully timed because an error of 1 second in time introduces an error at the equator of ¼ nautical mile in longitude. Several consecutive observations are made on the same body and more than one body should be observed for precise work. Celestial bodies should be chosen that may be observed near the prime vertical and at altitudes ranging from 30° to 60° above the horizon.

Longitude observations are subject to greater error than those for latitude, but several careful observations should locate a point within ½ minute or less. An error of 1 minute of arc at the equator is equivalent to an error of 1 nautical mile or 1,850 meters. Longitude observations may be calculated in 30 minutes or less, with a decided reduction for subsequent observations of the same body. One familiar with Dreisonstok tables could further reduce this time.

PHILIP ANDREWS

NEVADA CITY, CALIFORNIA
November 3, 1931

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 1 (JANUARY, 1932), PP. 101-102

DISCUSSION

FRIO CLAY, SOUTH TEXAS

On pp. 967-970, No. 8 (August, 1931), of this *Bulletin*, is a report by a committee of San Antonio geologists (E. H. Finch, *chairman*, Phillip F. Martyn, Olin G. Bell, and R. F. Schoolfield) on certain problems of nomenclature concerning the Frio and adjacent formations of Tertiary age in South Texas. As the conclusion of some correspondence between this committee and the acting director of the United States Geological Survey, we are pleased to quote from a letter, dated September 28, 1931, written by W. C. Mendenhall to Mr. Finch.

I believe that there is substantial agreement to the following statements:

(1). There are two stratigraphic units in the interval between the Fayette below and the Oakville above, which should be and have been mapped, and therefore need separate names.

(2). The upper and larger unit consists chiefly of volcanic material, though Dumble did not recognize the fact that it had that character. It was included in, if it did not entirely constitute, Dumble's Frio clay and was named Gueydan by Bailey when he recognized its lithologic character and separated the underlying unit from it. After an attempt to restrict the name Frio to it apparently all are now happily agreed that it is the southward continuation of the Catahoula formation and that it shall be called the Catahoula tuff.

(3). The unit between the Catahoula tuff and the Fayette was mapped separately by Bailey under the name Frio clay. This was admitted to be a decided restriction of the original Frio, and this is the usage recommended by the San Antonio Geological Society's committee. The United States Geological Survey, on the recommendation of its field geologists, considered this a greater modification of the original description than is desirable and adopted the new name Yeager instead of Frio in the belief that this would cause less confusion than any other course.

The remaining question then is that of the name to be applied to the clay beneath the Catahoula tuff.....The Geological Survey as represented by its Committee on Geologic Names, is still of the opinion that it is debatable whether Dumble's original Frio included the clays under the Catahoula tuff; it appears to the committee that all of Dumble's featured outcrops, those which he actually saw and on which he based his description of the Frio clay, fall within the volcanic beds which we have agreed should be called the Catahoula tuff. If this is true, the use of Frio for the nonvolcanic clays would seem to be the transference of the name from a unit that was seen and described by the author to another that, if seen at all by him, was only obscurely understood. The committee believes that, in view of the differing uses of Frio by various authors, a new name would be least likely in the long run to lead to misunderstanding and confusion.....

A careful perusal of Dumble's 1894 paper will convince you, I am sure, that his reference to volcanic beds on page 555, pertains to the Fayette formation, and not to the Catahoula tuff.....

On the other hand, the question of the specific name to be used is not a matter of first importance, for after all, the names of formations are but tools for our work and not an end in themselves. If everyone clearly understands the meaning of a name its purpose is served. We all realize that strict priority and rigid adherence to original definition must often yield to usage, and that the rules of stratigraphic nomenclature must be kept more flexible than those that, for example, govern biologic nomenclature. In the particular case in hand, in deference to local usage and the wish of the San Antonio Geological Society as expressed by you, and of other geologists in the area in-

volved, the Geological Survey is willing to waive its opinion..... I therefore am approving the use by the Survey of the term Frio clay instead of Yeager clay for the formation beneath the Catahoula tuff and above the Fayette sandstone.

Briefly, then, the decision has been reached by the U. S. Geological Survey to use "Catahoula tuff" for Bailey's "Gueydan," and to retain "Frio clay" for the formation between the Fayette sandstone below and the Catahoula tuff above. This is in conformity with the San Antonio Committee's recommendation.

F. H. LAHEE

DALLAS, TEXAS
November 27, 1931

PERMO-CARBONIFEROUS OROGENY IN SOUTH-CENTRAL UNITED STATES

CORRECTION

E. H. Sellards advised the writer that the effect of his paper in the *Bulletin* of September, 1931 (p. 1038), and of his statement on page 70 of the publication by the Royal Academy of Sciences of Amsterdam ("The Permo-Carboniferous Orogeny in the South-Central United States," Vol. 27, No. 3) is to credit discovery of the overthrusting in the Solitario region to C. L. Baker, but that this is incorrect, as overthrusting in that region was made known as the result of work by Sellards, Adkins, and Arick, and is shown on maps which these authors placed in circulation during 1930.

The writer wishes to correct this unintentional oversight.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT

HAINFELD CASTLE
FELDBACH, STEIERMARK
October 26, 1931

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 1 (JANUARY, 1932), PP. 103-110

REVIEWS AND NEW PUBLICATIONS

Petroleum in the United States and Possessions. By RALPH ARNOLD and WILLIAM J. KEMNITZER. (Harper and Brothers, New York and London, 1931.) xxi+1052 pp., 91 tables, 39 illus. 6½ × 9½ × 2¼ inches. Cloth. Price, $16.00.

The sub-title is, "A presentation and interpretation of the salient data of geology, technology, and economics of petroleum in each state and possession treated according to the conventional major field divisions."

This monumental compilation of data concerning the occurrence and production of oil and gas is the most excellent and most complete ever published. It supplies a ready reference work replete with tabular and graphic statistics, bibliographies, and indices complete through 1929. Divisions of the book are: petroleum in productive areas, 855 pages; petroleum in non-productive areas, 137 pages; index of authors, 9 pages; index of subjects, 24 pages; index of text, 20 pages. The frontispiece is a folded outline map of the United States (7 × 10½ inches) in 4 colors, showing proved oil and gas fields, impossible, unfavorable, and prospective areas. The book is embellished with a folded geological map of the United States (7 × 10½ inches) in 18 colors, redrawn from the latest available data.

Oil producers, technologists, and geologists will find this volume an indispensable reference work. It has been prepared with great care and with the advice of leading authorities throughout the country. It is remarkably well written and edited and the few errors, principally in the spelling of place names, do not affect the value of the text. The bibliographies are the best ever prepared and are invaluable to the exploration geologist.

Each producing state or unit is treated under the following headings, subheadings following in parentheses: historical review, with chronological list of all fields; geological review (distribution and number of oil and gas fields with an alphabetical list, character of the oil and gas); stratigraphy (general outline, source rocks, reservoir rocks, with generalized stratigraphic sections); structure; physiography and geography; classification of land for oil and gas; technological and statistical review (exploration, development, drilling, production); review of economics (price, investment, return); future possibilities; acknowledgments; source of information; selected references.

Detailed criticisms follow. The absence of state maps is unfortunate, and the expenditure for the beautiful geological map might perhaps better have been divided among uncolored state maps locating the oil and gas fields tabulated in the text. "Physiography and geography" might have been omitted. Source rocks at the present time might be termed a "necessary evil" in petroleum geology and the generalizations regarding them (p. 16) are so misleading that they should have been revised to agree with the subsequent text. The generalizations about reservoir rocks (same page) suffer from over-con-

densation. The "Stratigraphic distribution of petroleum" (p. 15) omits Eocene oil in the Gulf Coast, Mississippian oil in the Rocky Mountains, and Devonian oil in the Mid-Continent. The "Wilcox" sand of Oklahoma is Ordovician (p. 393), and the Big Lake, Texas, deep "pay," is also Ordovician (p. 429). In Texas and Louisiana there are no "Red River" and "Caddo" faults (p. 430). The Reynosa escarpment of Texas (p. 431) is a physiographic feature.

The Mid-Continent area is defined to include Arkansas and all of Louisiana and Texas except a narrow belt along the Gulf Coast. Such a division as stated in the text is not in accordance with general practice and has led to inadequate and inaccurate generalizations about the occurrence of petroleum (p. 332). In that part of the Mid-Continent area in which Paleozoic rocks crop out, including southeastern New Mexico, the stratigraphic importance of oil production is (1) Pennsylvanian, (2) Ordovician, (3) Permian, (4) Mississippian, (5) Siluro-Devonian.

Descriptions of the Rocky Mountain area do not emphasize the fact that most of the production has come from the Upper Cretaceous. Most geologists will not agree that "The source of petroleum in Wyoming is believed to have been primarily in the organic shales of 'Permo-Carboniferous' or older age" (p. 613).

SIDNEY POWERS

TULSA, OKLAHOMA
October 26, 1931

Erdöl. Allgemeine Erdölgeologie und Überblick über die Geologie der Erdölfelder Europas (Petroleum. General Petroleum Geology and a Short Account of the Geology of European Oil Fields). By O. STUTZER. (Gebrüder Borntraeger, Berlin, 1931.) Large octavo, 628 pp., 199 figs. Price, $15.00; special to A. A. P. G. members, $11.25.

This book is essentially a compilation of the literature on the subject. Most of it is devoted to the principles of petroleum geology, illustrated to a large extent by examples quoted from articles published recently in the *Bulletin* of The American Association of Petroleum Geologists. The book is well illustrated, not only by many examples, but also by the character of the diagrams used, most of which are redrawn and simplified from the original printed figures.

The work begins with a brief description of the chemical and physical nature of petroleum and gas, followed by a short discussion of the physical characteristics of the sediments in which oil occurs, such topics as porosity, permeability, compaction, and types of reservoir rocks being discussed. About one-fourth of the book is devoted to concise descriptions of the types of structures in which petroleum accumulates, the following topics being discussed: anticlines, synclines, faulted folds, salt domes, igneous intrusions, buried hills, terraces, faults, lenticular sands, differential porosity of sands, unconformities, and asphalt-sealed monoclines. This section is followed by descriptions of the manner of occurrence of gas, and of the chemical characteristics of ground

water. Next follow discussions of surface indications of petroleum, geothermal gradients, and origin of oil. The section on petroleum geology concludes with accounts of the recovery of oil, estimation of petroleum reserves, and miscellaneous drilling problems, such as location of wells and crooked holes.

The part devoted to European oil fields gives a summary of the geologic conditions in the producing fields, and offers the reader a good approach to the study of any particular European field. The descriptions are concise; they comprise a brief account of the stratigraphy, structure, producing horizons, history of production, character of oil, and references to the literature. Of special interest are the discussions of recent developments in the Baku, Grosny, and Kuban fields in Russia.

The chief attractions of this book are its wealth of recent references, its account of European oil fields, and the simple style of German in which it is written. The section devoted to the principles of petroleum geology, though systematically arranged and comprehensive, does not offer much that is unfamiliar to the careful reader of the publications of The American Association of Petroleum Geologists.

PARKER D. TRASK

WASHINGTON, D. C.
October, 1931

Oil Well Completion and Operation. By H. C. GEORGE. (University of Oklahoma Press, Norman, 1931.) 234 pp., 52 figs. 7½ × 10¾ inches. Cloth. Price, $3.00.

This book, published under a coöperative agreement between the United States Bureau of Mines and the State of Oklahoma, presents in an orderly sequence essential facts concerning oil-well completion and operation. A simplified style facilitates clear understanding by the layman. However, assembled facts from various authoritative sources, carefully digested, provide a ready reference and instruction for experienced operators and technologists.

Beginning with a chapter on oil sands and production relations, the author continues with discussion of modern drilling, completion, and casing methods. Factors affecting recovery, including sand texture and porosity, shooting, formation water, propulsive media, and physical and chemical properties of crude oil, are described, particularly in relation to efficient extraction of oil from the reservoir. Under production methods, much valuable and practical information is devoted to flowing, swabbing, and pumping wells. Chapters on oil-field emulsions, paraffine, and cleaning-out methods are written in the light of actual production experience. The final chapter on oil-well rejuvenation considers increased recovery methods, such as water flooding, use of vacuum, and repressuring of oil sands.

Throughout the book adequate description is made of ordinary well equipment with illustrations. The causes and effects of mechanical and production troubles and methods of prevention and remedy are discussed. The problems assuming major importance with increasing development difficulties during recent years, such as crooked holes, casing leaks, corrosion, deep-well produc-

tion, handling of large volumes of water, and floating sand, are discussed from the current point of view. The securing of maximum ultimate production, methods for preventing waste and for improving production are emphasized.

In conclusion, the various chapter subjects are made current and pertinent to modern production practice through close contact with field problems and a survey of improved practices.

H. H. POWER

TULSA, OKLAHOMA
October, 1931

Geologie en Geohydrologie van het Eiland Curaçao (Geology and Geohydrology of Curaçao). By GERARD JOHAN HENDRIK MOLENGRAAFF. Drukkerij J. Waltman, Jr., Delft (1929). 126 pp., 28 pls., geologic map, and sections.

Molengraaff has given us an exhaustive study of the geology, petrology, and especially the tectonics of this small island. Although his synclines are more probably areas of block faulting, his interpretation of general tectonic trends in this and adjacent regions is a most welcome addition to the scanty literature.

MARGARET C. COBB

NEW YORK CITY
October 23, 1931

"Oil and Sulphur Development in the Texas and Louisiana Gulf Coast Salt Dome Region," *Texas Gulf Coast Oil Scouts Association and South Louisiana Oil Scouts Association* (Houston) *Bull. 1, 1930* (1931). 128 pp., maps, sections, and tables.

The oil scouts have compiled and released in this volume much information available but attenuatedly scattered through the oil trade journals, many data extractible only with difficulty from oil company files by outsiders, and some important data available only in the files of the large oil companies which maintain an extensive paleontological department. Many statistical tables are given of the history, discovery, and salt-dome data of many of the salt domes, production and development, pipe-line outlets and capacities, available storage. There are special articles on the history of the individual salt domes and on several salt domes not previously described. The article on "The Geology of the Gulf Coast Area of Texas and Louisiana" (generally understood mainly to be by Teas) is the best general presentation of Gulf Coast stratigraphy available. The Bulletin should be in the libraries of oil companies, geologic departments of universities or oil companies, or geologists who are interested in the Gulf Coast.

DONALD C. BARTON

HOUSTON, TEXAS
November, 1931

Deep Borehole Surveys and Problems. By M. H. HADDOCK. McGraw-Hill Book Company, Inc., New York (1931). 296 pp., 186 figs., 17 pls. Price, \$4.00.

This book is a very serviceable compilation of information on many methods and instruments devised for measuring the deviation of boreholes from the vertical (or from the horizontal), and for securing oriented cores. A good idea of its scope may be obtained from the titles of its 12 chapters, as follows: (1) Deviation and its Causes; (2) Auxiliary Registrations in Borehole Surveys; (3) Instrumental Survey of Boreholes; (4) Core Orientation; (5) Fluid Methods of Surveying Boreholes; (6) Compass and Plumb-Bob Methods; (7) Pendulum Methods; (8) Photographic Methods; (9) Gyroscopic Compass Methods of Surveying Boreholes; (10) Geophysical Methods of Investigating Boreholes; (11) Problems; (12) Bibliography.

The author, who is principal of the Mining and Technical Institute of Coalville, Leicester, England, has endeavored to cover many types of boreholes, not only those drilled for oil, but also test holes for locating and mapping ores, coal, and mineral deposits; holes for sundry purposes in connection with mining operations, and especially the holes bored for the freezing process of mining. For the petroleum engineer and petroleum geologist, the preliminary treatment of causes, methods, and principles (Chapters I, II, III) seems to be a little insufficient.

To be more explicit, in the reviewer's opinion, the causes of deviation of boreholes from their intended course should be more fully discussed, with particular emphasis on the serious consequences of too much pressure on the bit during drilling. The causes cited (pp. 15-19) might well have been classified as (1) mechanical and (2) geological, since the distinction is often helpful. The difficulties attending the taking of oriented cores might have received fuller treatment (pp. 19-21). Of very practical importance is the question as to what minimum angle of deviation should be required for different depths of drilling. This is too briefly mentioned (p. 46). Furthermore, the method cited, of specifying a "limiting permissible error in verticality of 1 part in 100" (p. 46) is not as simple as a limiting vertical *angle* of deviation.

A useful list of requirements for any successful well-surveying device is given on pp. 46 and 47.

Quite proper, but too brief reference is made (p. 50) to the important fact that keeping a hole straight by regularly repeated measurements of its attitude during the progress of the drilling is generally more economical than completing its drilling and then determining its position by an accurate survey, with the probable sequel of financial losses if it is crooked.

In describing the many methods of borehole surveying in Chapters IV-X, more reference might well have been made to methods of lowering the recording devices, whether by drill stem or cable or otherwise, and whether in open hole, in cased hole, or through the drill stem itself.

The reviewer has searched in vain for a discussion of the mechanics and mathematics of a long suspended string of pipe in vertical holes, in holes curving off the vertical in a vertical plane, and in holes with helical wanderings.

An excellent feature of the book is the mention of both advantages and disadvantages of each instrument and method described. For those who are

interested in the practical side of borehole surveying, a classification of instruments and methods according to whether they are for measuring only angle of deviation from the vertical, or both angle and direction of such deviation, would be useful.

Familiar in our country where drilling for oil is in progress, such methods and instruments as Anderson's California method of surveying, Hanna's apparatus, Macready's method of taking oriented cores, the Driftmeter, Kinley's inclinometer, and the Surwel gyroscopic clinometer, are described. In a treatise as complete as this, it seems strange that no mention is made of the simple and useful "syfo" instrument, now widely employed as a substitute for the older acid-bottle method.

The type and make-up of the book are excellent. Relatively few errors were noticed. We call attention, however, to several misspelled proper names. On p. 91, Riemer should read Rieber. On pp. 277, 278, and 294, Milliken should read Millikan; and on p. 284, Chamberlain should read Chamberlin. The language is in places obscure. On p. 224 we read "the survey is plotted in one vertical section and two horizontal ones, respectively, north-south and east-west and a model constructed if needed." Other instances might be noted.

The bibliography is comprehensive. The index is too brief. For example, there is no reference that we can find to the deviation permissible in drilling, a topic of sufficient practical importance to warrant its inclusion in the index. Many other items are similarly omitted.

In spite of the deficiencies noted, the volume will be of value to all those interested in well surveying.

F. H. Lahee

Dallas, Texas
November 21, 1931

Report on Tour of Inspection of the Oil Fields of the United States of America and Argentina and Oil Prospects in Australia. By W. G. Woolnough. 119 pp., 36 illus. Government Printer, Canberra, F. C. T., Australia (1931).

Professor Woolnough gives a most interesting and readable brief account, simply stated but thorough, of the American oil geology and exploration. It is most interesting to see ourselves as an impartial observer sees us. The reviewer fancies, perhaps, that there is a little predominance of an Oklahoma-California flavor to Professor Woolnough's impressions and feels that some of Professor Woolnough's impressions are only half true, that not all American geologists' work is quite so super-perfect, but that, as a whole, Professor Woolnough has very successfully caught the spirit of the American oil production business. The report will be read with interest by any American oil geologist, with profit by almost any general geologist and by foreign geologists; and might well be required as collateral reading for all graduate students in geology.

Donald C. Barton

Houston, Texas
November, 1931

RECENT PUBLICATIONS

ARGENTINA

"Eine Woche in den Ölfeldern von Comodoro Rivadavia" (A Week in the Oil Fields of Comodoro Rivadavia, Argentina), by G. Aslan-Zumpart. *Petrol. Zeits.* (Berlin), Vol. 27, No. 44 (November 1, 1931), pp. 795-98; 7 figs., including geological cross section.

"Fallas y Petróleo en la Antigua Zona de Reserva Fiscal de Cinco Mil Hectáreas de Comodoro Rivadavia" (Faults and Petroleum in the Antigua Zone of the Federal Reserve of Five Thousand Hectares), by Enrique Fossa-Mancini. *Del Boletin de Informaciones Petrolíferas* (Buenos Aires), Vol. 8, No. 84 (August, 1931), pp. 1-21; 8 figs.

"Breve Reseña de las Investigaciones Geológicas Realizadas por los Geólogos de la Dirección General de Yacimientos Petrolíferos Fiscales, entre Marzo de 1927 y Marzo de 1931" (Brief Résumé of Geological Investigations Made by the Geologists of the Director General of the Federal Petroleum Fields between March, 1927, and March, 1931), by Enrique Fossa-Mancini. *Contribuciones a la Primera Reunión Nacional de Geografía* (Buenos Aires, May-June, 1931), pp. 1-27; 1 fig.; 4 plates.

AUSTRALIA

Report on Tour of Inspection of the Oil-Fields of the United States of America and Argentina, and on Oil Prospects in Australia, by W. G. Woolnough. Department of Home Affairs, Canberra, Australia (1931). 119 pp., 36 photographs. 12⅛ × 8¼ inches. Paper. Price, 5 s.

CALIFORNIA

"Catalogue of the Marine Pliocene and Pleistocene Mollusca of California and Adjacent Regions with Notes on their Morphology, Classification, and Nomenclature and a Special Treatment of the *Pectinidae* and the *Turridae* (Including a Few Miocene and Recent Species) Together with a Summary of the Stratigraphic Relations of the Formations Involved," by U. S. Grant, IV, and Hoyt Rodney Gale. *Memoirs San Diego Soc. Nat. Hist.* (San Diego, California), Vol. 1 (1931). 1,036 pp, 4 diagrams, 3 tables, 15 text figs., 32 plates. Paper. 11½ × 9 × 2⅜ inches. Price, $8.00.

COLOMBIA

"Exploración en la región de Apulo-San Antonio-Viotá" (Exploration in the Region of Apulo-San Antonio-Viotá), by Enrique Hubach. *Boletin de Minas y Petróleo* (Bogota), Vol. 4, Nos. 25-27 (January-March, 1931), pp. 41-59, map of areal and structural geology.

COLORADO

"The Paleontology of the Denver Quadrangle, Colorado," by J. Harlan Johnson. *Proc. Colorado Sci. Soc.* (Denver), Vol. 12, No. 11 (1931), pp. 355-78.

EUROPE

"Zur Bildung der Europäischen Erdöllagerstätten" (Formation of European Petroleum Deposits), by August Moos. *Petrol. Zeits.* (Berlin, October, 1931), pp. 711-24.

Das Alpine Europa, ein geologisches Gestaltungsbild (Alpine Europe, a Geological History), by L. Kober. Gebrüder Borntraeger, Berlin (1931). 310 pp., 33 text figs., 3 pls. in pocket. 7 × 10½ inches. Price: paper, 20 R. M.; cloth, 22 R. M.

FRANCE

"Rapport sur la prospection pétrolifère du basin oligocène de Narbonne (Petroleum Possibilities in the Oligocene Basin of Narbonne), by L. Barrabé. *Annales de l'Office National des Combustibles Liquides* (Paris), Vol. 6, No. 3 (May-June, 1931), pp. 471-76; 2 figs.

GENERAL

Deep Borehole Surveys and Problems, by M. H. Haddock. McGraw-Hill Book Company, Inc., New York (1931). 296 pp., 186 figs. 9 × 6 inches. Cloth. Price, $4.00.

"The Permo-Carboniferous Orogeny in the South-Central United States," by W. A. J. M. van Waterschoot van der Gracht. *Der Koninklijke Akademie van Watenschappen te Amsterdam Afdeeling Natuurkunde,* Tweede Sectie, Deel 27, No. 3 (1931). N. V. Noord-Hollandsche Uitgevers-Maatschappij, Amsterdam, Holland. In English. 170 pp., incl. bibliog. and index; 9 pls., 15 tables. 7 × 10¼ inches. Paper.

"Notizen zur Ölgeologiè und Salztektonik" (Notes on Petroleum Geology and Salt Tectonics), by Karl Krejci. *Petrol. Zeits.* (Berlin), Vol. 27, No. 48 (December 1, 1931), pp. 893-97.

ITALY

"Le Prospettive petrolifere dell'Italia" (Italian Petroleum Prospects), by Stanislaw Zuber. *Echi e Commenti* (Via Emanuele Gianturco, 5, Rome), 5-25 Giugno 1931-IX.

LOUISIANA

"Engineering Report of Cotton Valley Oil Field, Webster Parish, Louisiana," by J. S. Ross. *U. S. Bur. Mines Tech. Paper 504* (1931). Supt. Documents, Washington, D. C. Price, $0.30.

MANCHURIA

"The Oil Shale Deposit of Fushun, Manchuria," by Kunio Uwatoko. *Jour. Faculty of Sci. Hokkaido Imp. Univ.* (Sapporo, Japan). Ser. 4, Vol. 1, No. 2 (September, 1931). Pp. 115-206; 38 figs., 13 pls.

PENNSYLVANIA

"Gas in the Tioga Region, Pennsylvania," by George H. Ashley and Stanley H. Cathcart. *Pennsylvania Topog. and Geol. Survey (Harrisburg) Bull. 102 A* (December 1, 1931). 13 mimeog. pp., 2 maps. Part B is separate, dealing more fully with technical geologic data. Price for postage, $0.06.

PERSIA

"Salzstöcke in Persien" (Salt Masses in Persia), by F. Mürriger. *Petrol. Zeits.* (Berlin), Vol. 27, No. 44 (November 1, 1931), pp. 799-802; 2 figs. From Institut f. Brennstoffgeologie an der Bergakademie Freiberg.

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VOL. 16, NO. 1 (JANUARY, 1932), PP. 111-114

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

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Kimio Uyemura, Tokyo, Japan
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Richard V. Hollingsworth, Norman, Okla.
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John Lewis Porter, Long Beach, Calif.
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Wilbur Houston Seifert, Greensburg, Pa.
Chas. R. Fettke, R. E. Sherrill, Roswell Johnson

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Harve Loomis, E. W. Hummel, G. C. Gester
Harry Cameron Kennard, Ciudad Bolivar, Venezuela, S. A.
C. M. Crebbs, P. E. Nolan, C. A. Baird

PACIFIC SECTION ANNUAL MEETING, NOVEMBER, 1931

The Pacific Section of the Association held its eighth annual meeting at the Biltmore Hotel, Los Angeles, California, November 5 and 6, 1931. M. G. Edwards, retiring president, presided. C. M. Wagner was chairman of the program committee. Outgoing officers of the section are M. G. Edwards, president, and L. N. Waterfall, secretary-treasurer. Officers elected for the

new year are: C. M. Wagner, president, General Petroleum Corporation, Los Angeles, and Herschel L. Driver, secretary-treasurer, 630 Palm Drive, Glendale.

The following papers were presented on the program of the section.

"The Problem of the Area of the Lost Hills and South Dome of Kettleman, San Joaquin Valley," by Harold M. Horton

"Periods of Folding in the Temblor Range, Kern County, California," by Gerard Henny

"Progress of Geologic Branch of the California State Division of Mines," by Olaf P. Jenkins

"Some Structural and Commercial Oil and Gas Possibilities of California's Central Valley Region," by Walter Stalder

"A Few Suggestions Concerning Methods of Developing Geologic Structure Sections from Surface Data and Their Relation to Subsurface Structure in a Few California Oil Fields," by J. W. E. Hanes and Bruce Seymour

"Limitation of Ground Water as an Aid in the Determination of Hidden Geologic Structures," by E. K. Soper

"The Stratigraphy of the Santa Maria District," by L. M. Clark

"The Structural History and Development of the Santa Maria and Lompoc Oil Fields," by Francis F. Bowman, Jr.

"The Structural History of Santa Barbara-Ventura Basin, with Brief Discussion of Faulting and the Origin of the Vaqueros and Sespe Oil," by W. E. James

"Problems in Miocene Correlation," by R. D. Reed

"The Geology of the Simi Oil Field, Ventura County, California," by Thomas F. Stipp

"Structural Features of the Seal Beach Oil Field," by Glenn H. Bowes

The following paper was presented by the Pacific Section of the Division of Paleontology and Mineralogy which met at the Engineers' Club.

"Correlation of the California Lower Miocene," by W. H. Corey

OKLAHOMA CITY MEETING, MARCH 24-26, 1932

The Oklahoma City Geological Society, W. H. Atkinson, president, 26th Floor, Ramsey Tower, Oklahoma City, has announced the appointment of chairmen of the several committees on local arrangements as follows.

General Committee, Irving Perrine, 16th Floor, Petroleum Building, Oklahoma City
Finance, C. H. Taylor, Braniff Building
Reception, W. L. Miller, 2900 Ramsey Tower
Registration, J. T. Richards, Petroleum Building
Ladies, Wm. H. Atkinson, 2600 Ramsey Tower
Publications, A. H. Richards, 1100 W. 38th Street
Trips, W. W. Clawson, I. T. I. O. Company
Exhibits, H. S. Thomas, Colcord Building
Entertainment, R. D. Jones, 812 E. 16th Street
Technical Program, G. C. Maddox, 2112 N. Villa
Golf, F. M. Ricks, 823 W. 16th Street
Publicity, Albert S. Clinkscales, Petroleum Building

F. H. Lahee, Box 2880, Dallas, Texas, general chairman in charge of the technical program, has appointed the regional associate editors (see page ix of the January *Bulletin*) as members of the main committee on the technical program. Manuscripts should be submitted in triplicate, typewritten in double- or triple-spaced lines, accompanied by brief abstract for publication

in the printed program. Authors should prepare manuscripts in accordance with instructions contained in the Association pamphlet on "Preparation of Manuscripts," a copy of which may be obtained from Association headquarters, Box 1852, Tulsa, Oklahoma. Authors who have not already submitted their complete manuscripts are requested to send, *now*, the following necessary preliminary information: (1) subject, (2) name, address, and business connection of author, (3) brief abstract, (4) approximate length of proposed paper, (5) number of minutes required for oral presentation of condensed paper, (6) number of illustrations (charts or slides), (7) when complete paper will be ready, and (8) whether it will be presented at the meeting in person, or by title.

The following preliminary list of papers is announced.

"Geology of Cuba," by J. Whitney Lewis

"Structural History of Seminole Uplift," by Ira Cram

"New Developments and General Oil Situation in North Germany," by Karl Hasselmann

"Boggy Creek Salt Dome, Anderson and Cherokee Counties, Texas," by E. A. Wendlandt and H. J. McLellan

"'Diapirism' and Relation to Water and Oil Levels in Oil Fields," by Charles Bohdanowicz

"Oil-Producing Situation in Poland During 1930 and 1931," by Charles Bohdanowicz

"Oil Occurrences and Recent Activities in North Africa," by Henry de Cizancourt

"Oil and Gas Prospects of St. Lawrence Valley, between Montreal and Quebec," by L. C. Snider

"East Texas," by———

"Types of Great Plains Structure, Northern United States," by C. E. Dobbin and C. E. Erdmann

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Memorial

HOWARD WALDE KITSON

Howard Walde Kitson died at Los Angeles, California, August 8, 1931, at the age of forty-eight.

After attending public school in New York, which was the city of his birth, Mr. Kitson was a student at the School of Mines of Columbia University, 1904-1909, where he was graduated in mining and geology. Upon graduation he devoted his time to mining work, principally in Missouri, Arizona, and Mexico. In 1918, he published a paper on the geology of the Joplin district, southwest Missouri, now incorporated in the text, "Practical Mining." At college he was a member of the Phi Kappa Psi fraternity, and later was elected to membership in the American Institute of Mining and Metallurgical Engineers, the Society of Economic Geologists, and The American Association of Petroleum Geologists. He is survived by his wife, a writer of note, and a daughter.

Kitson served in the Navy during the World War, and, following his discharge, became interested in oil exploration in Texas and New Mexico. He removed to California in 1922, and was engaged in geological work in the oil industry until the time of his death. His main interest while he was occupied as petroleum geologist was in the dynamic phases of structural deformation, and he devoted several years to laboratory and field research. He carried on this work for three years while in the employ of a major oil company, continuing his research studies privately after resigning from the company. The results of these investigations were to be published this fall, and two noted physicists were collaborating with Mr. Kitson in checking his mathematical reasoning. It is to be hoped that this paper, which will be a valuable contribution to science, may still be published.

Those who knew Howard Kitson intimately admired him for his brilliant mind, his scholarly attainments in mathematics, physics, and geology, and his great capacity for consistent hard work. Believing firmly that his research would lead to the solution of some of the fundamental problems of structural geology, Kitson pursued his studies with admirable determination, regardless of personal gain. Those of us who were his close friends liked him for his fine unselfishness, his deep personal loyalty, and his uncomplaining stoicism under physical adversity. In his death at the most productive period of mature manhood, the geological profession suffered a severe loss. Kitson's place is one which will not easily be filled.

IRVINE E. STEWART

LOS ANGELES, CALIFORNIA
October, 1931

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 1 (JANUARY, 1932), PP. 117-118

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

M. M. KORNFELD, of Tulsa, Oklahoma, is the author of "Recent Littoral Foraminifera from Texas and Louisiana," a paper constituting No. 3 (October 15, 1931) of Vol. 1 of *Contributions from the Department of Geology of Stanford University.*

W. T. THOM, JR., of the geological staff of Princeton University, participated in the Third International Conference on Bituminous Coal at Pittsburgh last November, with a paper on "Interrelationships of Coal, Petroleum, and Natural Gas."

E. A. STILLER, of the Arkansas Natural Gas Corporation, read a paper on "Deep Gas Production in the Bethany Gas Field, Panola County, Texas," before the Shreveport Geological Society, November 6, 1931.

DAVID DONOGHUE, of Fort Worth, spoke on "Geologists and Their Relationship to Business and Politics," at the regular meeting of the West Texas Geological Society, San Angelo, Texas, November 7, 1931.

A. J. BAUERNSCHMIDT, JR., is geologist in the General Land Office of the U. S. Department of the Interior, with headquarters at Denver, Colorado.

R. P. MCLAUGHLIN, of Los Angeles, is now an underwriter for the Mutual Life Insurance Company at 815 South Hill Street.

The Tulsa Geological Society presented the following technical program during October and November: October 5, STUART K. CLARK, "Mechanics of Plains Type Folding of Mid-Continent Area"; October 19, ELFRED BECK, "The Julesburg Basin and Its Relation to the Rocky Mountains"; November 2, J. V. HOWELL, "History of Anticlinal Theory"; November 16, IRA CRAM, "Structural History of Seminole Uplift."

JOHN G. DOUGLAS, formerly of the Lago Petroleum Corporation, Maracaibo, Venezuela, has returned to the United States and is now teaching at the University of North Carolina, at Chapel Hill.

NOEL H. STEARN, consulting geologist of St. Louis, Missouri, and chief geologist for W. C. McBride, Inc., and the Silurian Oil Company, has been retained to report on the newly discovered quicksilver deposits in the Ouachita Mountains of Arkansas. He is co-inventor and developer of the Hotchkiss superdip magnetometer.

NOEL EVANS, formerly with the Gypsy Oil Company, is now located in Oklahoma City. His address is Corner Kelham and N. E. Twenty-First Street.

C. J. Haas is now employed by the Tulsa Oil Company as farm boss in East Texas. His address is General Delivery, Overton, Texas.

John R. Schwabrow, petroleum engineer with the U. S. Geological Survey, has been transferred from Shelby, Montana, to the Casper, Wyoming, offices.

W. G. Woolnough, geological adviser to the Commonwealth Government, Canberra, F. C. T., Australia, has an article entitled "Oil Prospects in Australia" in the November 14, 1931, issue of *The Petroleum Times*.

Harold M. Horton, geologist for the Superior Oil Company of California, has moved from Bakersfield to Dallas, Texas, to take up geological work in Texas and the Mid-Continent for the same company.

Robert H. Dott, consulting geologist, Tulsa, Oklahoma, has a paper entitled "Structural Mapping by Triangulation" in the November 27 issue of *The Oil Weekly*.

N. H. Darton, of the U. S. Geological Survey, spent the summer in the southwest obtaining data to complete a guidebook of the geology, et cetera, along the Southern Pacific Railroad from New Orleans to Los Angeles. It is intended that this work shall be published as a bulletin and that it shall serve also as a guidebook for part of the excursions of the International Geological Congress. The geologic and topographic maps of Texas have been submitted for publication.

L. G. Huntley and J. R. Wylie, of the firm of Huntley and Huntley, petroleum geologists and engineers, Pittsburgh, Pennsylvania, have a paper in the October-November issue of *Petroleum Technology*, entitled "Structural and Sand Conditions in Central New York."

Robert M. Whiteside, geologist for Shell Petroleum Corporation, Tulsa, addressed the Tulsa Geological Society, Monday, December 7, on "New Technique in Rotary Sampling."

Hubert G. Schenck, of the Department of Geology, Stanford University, California, has been elected to membership in The Geological Society of France.

George A. Macready, consulting geologist of Los Angeles, has a paper entitled "Geology of Washington State" in the December, 1931, issue of the *Oil Bulletin*.

Ross L. Heaton, consulting geologist, announces the removal of his office to 609 United States National Bank Building, Denver, Colorado.

Campbell Osborn, formerly engaged in the practice of law before the Federal Courts and Government Departments at Washington, D. C., and in oil and royalty corporation consultation and management in the Mid-Continent region, announces the opening of a general law office in Suite 527-30, Kennedy Building, Tulsa, Oklahoma.